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+ **Embedded Linux Made Easy**
and the hardware too

Stepper Motor Driver

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electrically
isolated**

+ **Computer-driven Heliostat**
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+ **Dual Hot-wire Anemometer**
Pitot tube reduces energy loss

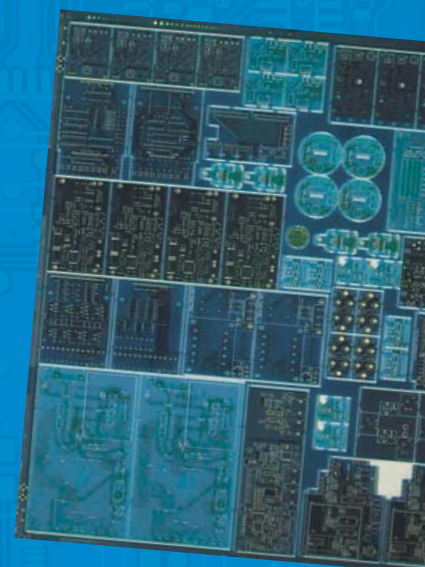


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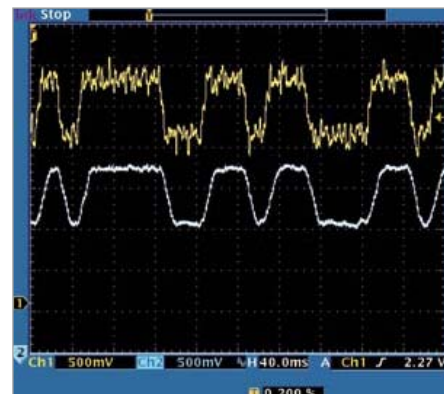
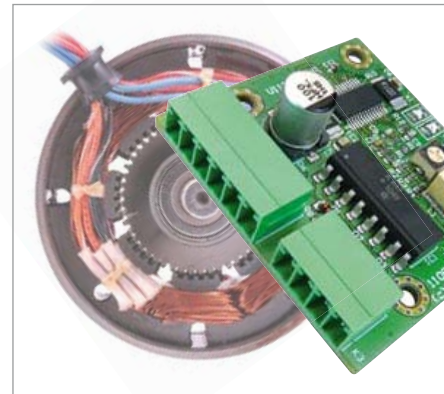
Unexpected Triggering Enabled

Typically, yet much appreciated, most of the emails and letters I receive every month start with the odd compliment on Elektor's "wide range of interesting subjects", and then go on to describe a problem of a technical or linguistic nature. When replying and supplying the information desperately needed by the correspondents, I am always curious to know their preferences in electronics, as well as what they mean by "wide". Those few readers replying to me typically wish to have a magazine that covers all of the following: simple as well as complex projects, theory alongside practice, expensive alongside cheap, scientific & kitchen table, SMD & leaded, kit & 100% home assembly, PIC & AVR, Windows & Linux, hardware & software, tubes & transistors, more NE555s, and so on. I believe the underlying request is for diversity and inspiration — if these parameters can be upheld by the magazine then the exact coverage is a secondary (yet terribly important) concern. Philosophy aside, this month's Nixie Thermometer / Hygrometer cheerfully combines vintage tube technology with analogue sensors and a microcontroller. Also, although you may not have an immediate need for a Heliostat (p. 38) or a Double Anemometer (p. 46) these articles provide useful thinkware for your own applications. Retronics and Hexadoku hopefully put a mild smile on your face, and the AVR SDR (p. 54) proves that you don't need the latest ARM Cortex-xyz for a profound understanding of digital radio. Trigger(s) Successful! And that's just six of them. Let me know how many of your personal trigger conditions were satisfied by this month's highly miscellaneous content.

Happy reading,
Jan Buiting, Managing Editor



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A combination of a Pitot tube and some clever electronics allows those elusive draughts in your home or office to be traced.



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14 Nixie Thermometer / Thermometer

Measuring temperature and humidity with a modern sensor and displaying the values on a retro display — it's all described in this article. A calibrated, 'digital' sensor provides data via its I²C interface to a microcontroller driving four Nixie tubes and automatically alternating between temperature and humidity, while providing a nice fading effect. It's a must-have!



28 Flexible Stepper Motor Driver

To enable the control of a stepper motor from, say, a parallel port of a PC, Elektor Labs have designed a compact driver PCB using the A3979 chip made by Allegro Microsystems. This chip has been specifically designed to control bipolar stepper motors in full-, half-, quarter- and sixteenth-step modes at currents of up to 2.5 A. The circuit is provided with optocouplers for electrical separation between the control inputs and the driver module



38 Computer-driven Heliostat

This project shows an example for a heliostat, built using two servo motors. The position of the sun with respect to time and the location on Earth is calculated using a mathematical model. The result is used to drive the servos and make them point in the direction of the sun or the stars.



54 AVR Software Defined Radio (4)

This month we turn our attention to something practical: using our DIY SDR to receive signals from DCF77 and other time reference transmitters, as well as the German weather service. We also investigate SDR-based time and weather signal decoding.

54 AVR Software Defined Radio (4)

Just when you thought that longwave and shortwave were old skool, we cover digital services received in these bands and decoded using our advanced DSP board.

60 Platino Controlled by LabVIEW (2)

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66 Electronics for Starters (6)

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72 2-Wire Interface for Illuminated Pushbuttons

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Elektor's monthly puzzle with an electronics touch.

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The Team

Managing Editor:	Jan Buiting (editor@elektor.com)
International Editorial Staff:	Harry Baggen, Thijs Beckers, Eduardo Corral, Wisse Hettinga, Denis Meyer, Jens Nickel, Clemens Valens
Design staff:	Thijs Beckers, Ton Giesberts, Luc Lemmens, Raymond Vermeulen, Jan Visser
Membership Manager:	Raoul Morreau
Graphic Design & Prepress:	Giel Dols, Mart Schroijen
Online Manager:	Carlo van Nistelrooy
Managing Director:	Don Akkermans

The Network



Our international teams

 United Kingdom Wisse Hettinga +31 (0)46 4389428 w.hettinga@elektor.com	 Spain Eduardo Corral +34 91 101 93 95 e.corral@elektor.es	 India Sunil D. Malekar +91 9833168815 ts@elektor.in
 USA Hugo Vanhaecke +1 860-875-2199 h.vanhaecke@elektor.com	 Italy Maurizio del Corso +39 2.66504755 m.delcorso@inware.it	 Russia Nataliya Melnikova 8 10 7 (965) 395 33 36 Elektor.Russia@gmail.com
 Germany Ferdinand te Walvaart +31 46 4389417 f.tewalvaart@elektor.de	 Sweden Wisse Hettinga +31 46 4389428 w.hettinga@elektor.com	 Turkey Zeynep Köksal +90 532 277 48 26 zkoks@beti.com.tr
 France Denis Meyer +31 46 4389435 d.meyer@elektor.fr	 Brazil João Martins +55 11 4195 0363 joao.martins@editorialbolina.com	 South Africa Johan Dijk +27 78 2330 694 / +31 6 109 31 926 j.dijk@elektor.com
 Netherlands Harry Baggen +31 46 4389429 h.baggen@elektor.nl	 Portugal João Martins +351 21413-1600 joao.martins@editorialbolina.com	 China Cees Baay +86 21 6445 2811 CeesBaay@gmail.com

Volume 38, Number 426, June 2012 ISSN 1757-0875

Publishers: Elektor International Media, Regus Brentford,
1000 Great West Road, Brentford TW8 9HH, England.
Tel. (+44) 208 261 4509, fax: (+44) 208 261 4447
www.elektor.com

The magazine is available from newsagents, bookshops and electronics retail outlets, or on subscription.

Elektor is published 11 times a year with a double issue for July & August.

Subscriptions: Elektor International Media,
Regus Brentford, 1000 Great West Road,
Brentford TW8 9HH, England.
Tel. +44 208 261 4509, fax: +44 208 261 4447
Internet: www.elektor.com/subs
Email: subscriptions@elektor.com
Rates and terms are given on the Subscription Order Form.

Head Office: Elektor International Media b.v.
P.O. Box 11 NL-6114-ZG Susteren The Netherlands.
Telephone: (+31) 46 4389444, Fax: (+31) 46 4370161

Distribution:
Seymour, 2 East Poultry Street, London EC1A, England.
Telephone: +44 207 429 4073

UK Advertising: Elektor International Media b.v.
P.O. Box 11 NL-6114-ZG Susteren The Netherlands.

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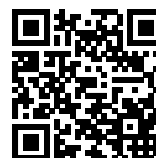
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Email: j.dijk@elektor.com
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Design the next innovation for Microchip in EAGLE V6 and win prizes (and glory!)

From May 1 to August 31, 2012 CadSoft and Premier Farnell are inviting design engineers to submit their design projects and win prizes with an overall value of around \$7,000 in the **EAGLE Design Challenge**. The competition is powered by Microchip and hosted on element14, the most innovative design engineer community for sharing electronic engineering solutions. Elektor and Circuit Cellar are acting as media partners.

Entering the competition is simple. To participate, applicants must ensure that all designs use EAGLE Version 6 and that a Microchip MCU or DSC will be integrated in the design. After registering on the element14 community users can submit a screenshot of their layout and add a description of their project on the competition page. Don't worry if you don't have an EAGLE license, to participate in the contest you can download a free 30-days trial version on www.element14.com/eagle-freemium.

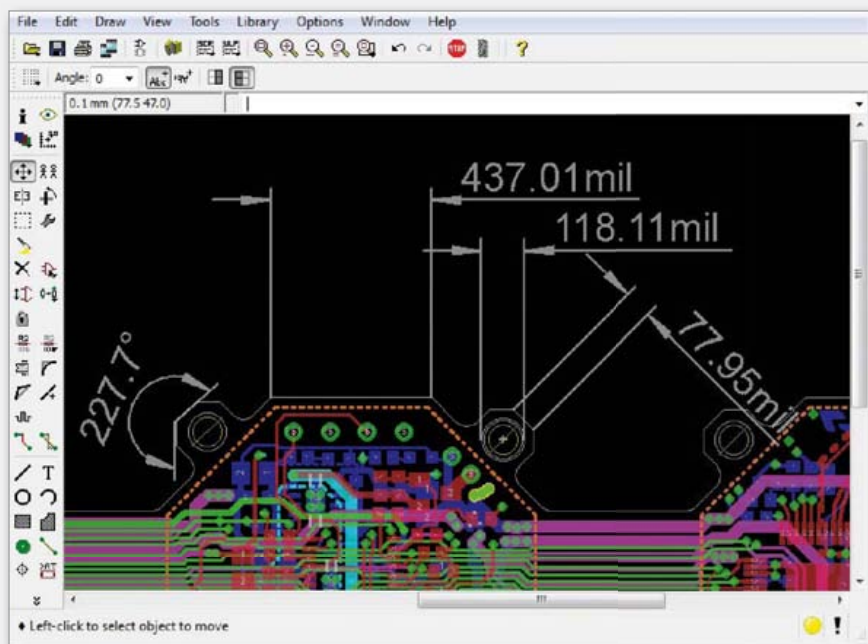
CadSoft EAGLE PCB design software is strongly established in the engineering community, recently awarded 'Product of the Year — Engineer Software 2012 Award' by German *Elektronik* magazine for the seventh time.

EAGLE version 6.1, released in January 2012 offers enhanced flexibility and enables users to save time through optimised and new features such as BGA escape routing, differential pair routing, automatic meanders and undo/redo logs. Additionally, the latest software provides automatic layout dimension, assembly variants, cut-out polygons, and a design reuse feature to merge board/schematic pairs using the PASTE function with full consistency.

The Prizes:

1. DELL Alienware M17x r3 + EAGLE version 6 Professional incl. all three modules.
2. MICROCHIP DV164037 Kit, Eval, ICD3 w/ Explorer-16 & DM163022-1 8-Bit development board + EAGLE Version 6 Professional incl. all three modules.
3. EAGLE Version 6 Standard incl. all three modules.

The outcome of the competition will feature peer-voting from the element14 community. Members of the world's leading technology community can 'like'



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entries and comment on the submission. Based on the community's 'likes' and comments, a panel of judges consisting of CadSoft, Premier Farnell and Microchip representatives along with independent EAGLE expert Prof. Dr. Francesco Volpe from the University of Applied Sciences in Aschaffenburg will pick the winners.

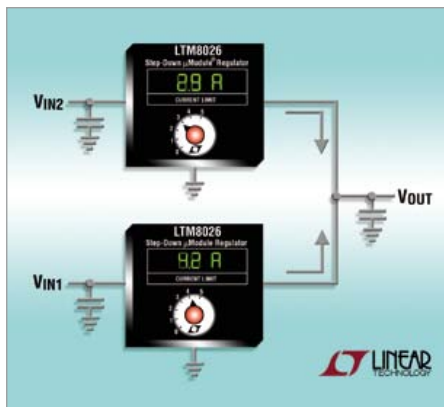
Judging criteria include clarity in description of the submission, its electronic concept, design complexity, design quality, and functionality.

For more details and terms and conditions please visit the link below.

www.element14.com/eagle-competition
(120355-1)

36 V, 5 A μ Module

Linear Technology's new LTM8026 is a 36 V input, 5 A step-down μ Module® regulator with an adjustable and precise ($\pm 10\%$) accurate current limit. The current limit enables designers to set the maximum amount of power drawn from the supply, preventing input voltage droop caused by overcurrent conditions. When multiple LTM8026 are configured with the outputs tied together, each converter can be programmed with a unique maximum current



limit to meet its specific input supply limitations for greater output power, a technique known as asymmetric power sharing. In contrast, common regulators must current share, a feature where each input supply contributes equally to the load, which is restricted by the least powerful input rail. Applications for the LTM8026 include point of load regulation in systems with 24 V and 12 V supplies such as VXI bus, for automotive, medical and industrial end-markets.

Like other Linear Technology μ Module regulators, the LTM8026 includes the DC/DC controller, power switches, power inductor, compensation and a modest amount of input and output capacitance in a surface mount package. The current limit is adjustable by applying a voltage or resistor divider and can be automatically decreased with rising junction or ambient temperature using a thermistor to prevent the LTM8026 or load from overheating.

The LTM8026 operates from an input voltage between 6 V to 36 V and regulates an output voltage between 1.2 V and 24 V set by a single resistor. In a 12 V to 3.3 V output application, the LTM8026 achieves an operating efficiency of 89% at 2 A. For noise-sensitive applications, the μ Module regulator can be synchronized to an external clock frequency in the range of 100 kHz to 1 MHz. Additional features include

Small CD player with lots of useful extras

Parasound, a San Francisco-based manufacturer of high-end audio components, has introduced the Zcd Compact Disc Player as part of its popular Z Custom line of rack-mountable components that are half the width of a standard 19-inch equipment rack.



While small in size, the Zcd has a high-performance Cirrus Logic DAC and a fully independent power supply for the analog circuits. With its built-in preamplifier functions, the Zcd and included remote control can be teamed with Parasound's Zamp v.3 class AB stereo amplifier and a pair of speakers to make a compact, high-performance audio system.

The Zcd plays conventional Compact Discs as well as MP3 files from a CD-R. It also functions as a basic DAC-preamplifier with a USB input for MP3 files on a flash drive. It has an analog 3.5 mm stereo line-input jack for portable players and other line-level sources. The Zcd has fixed and variable line outputs as well as coaxial and optical digital audio outputs. The source selection, track and MP3 file selection, and variable outputs are all operated via the supplied remote control. The Zcd volume adjustments are controlled by an independent analog volume control IC, not digitally inside the DAC.

The Zcd uses a 24-bit, 192 kHz-capable Cirrus Logic CS4353 DAC with a Cirrus Logic CS8416 digital receiver. The circuitry boasts fifth-order multi-bit delta-sigma architecture with low latency digital filtering. It also includes analog filtering and ideal differential linearity along with very high tolerance to clock jitter. The Zcd delivers excellent low frequency performance without external DC blocking capacitors. The analog circuits are powered by an entirely independent analog power supply with its own power transformer.

For custom installers, the Zcd has a rear-panel IR input and one-way RS232 serial control port. There are three turn-on options: manual, automatic when AC is supplied, and 12V trigger. There is even a 12 V trigger output to turn on a Zamp v.3 amplifier automatically.

Like all Parasound Z Custom components, it is one rack-space high and 9-1/2-inches wide; half of a standard rack width. It can be used with Parasound's SBS side-by-side bracket to link two Z Custom units together, or Zblank for mounting across one rack space. Parasound also offers its half-width Zrack for mounting up to five Z Custom components.

The Parasound Zcd is now available with a manufacturer's suggested retail price of \$400.

www.parasound.com (120332-X)

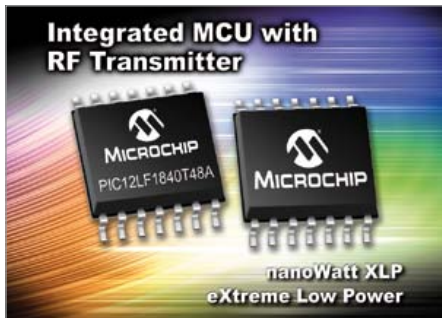
externally adjustable soft start, adjustable switching frequency and thermal shutdown.

The LTM8026 is packaged in a thermally efficient 11.25 mm x 15 mm x 2.82 mm LGA package. Two temperature grades, E and I for the -40°C to $+125^{\circ}\text{C}$ temperature range, are available for immediate delivery from stock.

www.linear.com/product/LTM8026
(120332-VII)

Integrated 8-bit MCU with RF transmitter on a single chip

Microchip's new PIC12LF1840T48A 8-bit microcontroller (MCUs) offers a single-chip solution for developing low power wireless designs. The combination of an extremely low operating voltage and compact 14-pin TSSOP package, make the PIC12LF1840T48A ideal for developing



low cost and extremely low power wireless applications such as remote keyless entry, security systems and remote monitoring. The first in a family of single-chip devices for wireless applications, the PIC12LF1840T48A microcontroller combines nanoWatt XLP power-saving technology with a 418/434/868 MHz RF transmitter. The PIC12LF1840T48A maximises battery life with a power-saving operating voltage of 1.8 V and extremely low current consumption in sleep mode. Efficient integration with the transmitter gives you fast wake-up and allows you to make full use of the microcontrollers 8 MIPS operation. Designers may also add Microchip's proprietary, royalty free KEELOQ® code hopping technology, an industry proven technology used worldwide by leading manufacturers, to provide additional security to their applications. The relatively small code size is highly configurable and can easily be scaled to provide secure solutions to various markets. In terms of development Tools, the following are available: MPLAB® PM3 Universal Device Programmer (DV007004); MPLAB ICD 3 In-Circuit Debugger (DV164035); MPLAB REAL ICETM PROBE KIT (DV244005); PICkitTM 3 In-Circuit Debugger (PG164130).

www.microchip.com/get/eut48a (120304-I)

Automotive-grade universal receiver and front end amplifier

Maxim's new MAX2769B and MAX2670, next-generation high performance solutions specifically designed to address Global Navigation Satellite System (GNSS) applications. These flexible receiver solutions are capable of operating over the navigation standards, GPS, GLONASS, Galileo, and Compass and have completed PPAP and

Pico USB Dr DAQ serves up a real 'tweet' for Wildlife Whisperer

An unusual collaboration between an online wildlife community and a technology company is giving people across the world an opportunity to witness the nesting habits of British birds.

Wildlife Whisperer, an online community created by TV presenter Simon King OBE and Jason Alexander, and Pico Technology, a test equipment manufacturer based in Cambridgeshire, have installed cameras, temperature and light sensors in bird boxes in a Suffolk garden. Images from the cameras, and data from the sensors, are streamed live to the Wildlife Whisperer website where the public can witness the day to day activities of nesting Great Tits and Blue Tits.

"Linking the temperature and light data with the images gives a different view on the birds nesting habits" said Jason Alexander, "particularly with the variations in temperature we have seen so far this year".

Pico's resident ornithologist, Hitesh Mistry, added "Watching the day to day activity of the birds is very interesting, and a unique use of one of our products".

Each bird box is fitted with a DrDAQ data logger, to measure temperature and light levels, and a video camera. Software running on a local PC collects all the data and streams this across the internet to the website where users can log on to see the live action. For budding ornithologists who wish to set up their own bird box monitoring stations kits are available from the website.

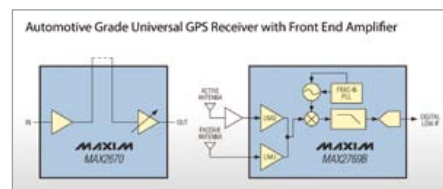
Summing up the collaboration Jason said "I must just say how thoroughly impressed I am with the help Pico have given so far and the way in which they keep their word with regards to getting back to me with updates etc. It's rare these days to find a company that consistently exceeds my expectations".

www.picotech.com www.drdaq.com www.wildlifewhisperer.tv (120304-IV)



AEC-Q100 approval.

The MAX2670 is a dual stage low noise amplifier typically located in or close to the antenna module, while the MAX2769B



resides within the dashboard as the receiver. The MAX2769B boasts the industry's lowest noise figure of only 1.4 dB, a critical element that dominates the overall receiver sensitivity and enables faster satellite locking. The MAX2670 is a highly versatile design that allows external filtering between first and second stage, providing flexibility for system optimization. Its high integration eliminates

large, expensive, discrete transistor solutions. Combining these two parts delivers a highly flexible, high performance and robust system solution for navigation applications. The MAX2769B and MAX2670 are designed on Maxim's advanced, low-power SiGe BiCMOS process technology to offer the highest performance and integration at the lowest cost. It is compatible with virtually all GNSS baseband hardware and GNSS software-based receiver designs.

The MAX2769B completely eliminates the need for external IF filters by implementing on-chip monolithic filters and requires very few external components to implement a low-cost GNSS RF receiver solution. In addition, its integrated ADC, which is programmable from 1 to 3 bits, makes it highly configurable and the most flexible receiver on the market.

www.maxim-ic.com (120304-III)

Signal generators meet the future wireless test challenges

The wireless industry is moving at its fastest ever pace with the rapid introduction of LTE, and now the fast pace for LTE-Advanced and new technologies in WiFi. To match this pace and provide effective test solutions designers must keep ahead so that they can effectively test new technologies such as MIMO, carrier aggregation (CA), multi band radio, and co-ordinated multi point transmissions. Achieving this requires a new generation of signal generator to create all of the required new reference signals in a compact and manageable integrated environment. This is needed to meet the technology and measurement challenges of Multi Standard Radio, Carrier Aggregation, and MIMO with multi-carrier transmissions.



Anritsu is the first test equipment supplier to release the new generation equipment that is following these market demands. The MG3710A is the newest product on the market, and supports unique new measurement techniques to support these latest wireless transmission standards. It is fully able to meet these challenges, and so it enables RF designers to verify that their products are also able to meet the challenges of next generation wireless technology. The unique features include 'waveform combining' to enable an engineer to quickly create more complex signal combinations from libraries of signals, and the dual RF capability that addresses the future needs of Carrier Aggregation and multi-carrier transmissions that are being developed for higher speed data links. The architecture allows for multiple units to be locked together in RF phase and signal clock, enabling the effective and simple implementation of test systems for high order MIMO configurations that are currently in development (e.g. 8x8 MIMO).

www.anritsu.com (120304-III)

Ambient light sensor for intelligent daylight harvesting

Recently, at the Light+Building exhibition in Frankfurt, Germany, austriamicrosystems introduced their TSL4531 ambient light sensor device family, which enables sophisticated daylight harvesting for intelligent lighting systems and luminaires.

The sensor family — developed by TAOS, the leading global supplier of intelligent light sensors acquired by austriamicrosystems in 2011, offers a wide sensitivity range from 3 lux to 220,000 lux, preventing saturation even in direct sunlight, while implementing a photopic response model that spectrally matches light perception in the human eye.

The TSL4531 ambient light sensor provides a simple, direct lux output and a 16-bit digital interface. Sophisticated filters automatically reject the 50-60Hz ripple typically produced by a building's fluorescent lighting systems, enabling the sensed light levels to more accurately measure the daylight that is entering the building.

Daylight harvesting is the next major step in the development of integrated lighting systems, enabling luminaires to dim in response to the amount of outside light that

is entering a building through windows or skylights. By supplementing the working space with only the amount of light needed to maintain a uniformly lit environment, energy savings of 30% or more can be realized when compared to existing installations which do not respond to changes in ambient light.

Being fully aware of the lit environment also allows optimization that extends beyond energy savings. In integrated building management and control systems, the combination of proximity/motion and light sensing provides an abundance of data concerning the interior environment. Additionally, daylight sensing/harvesting combined with precise control mechanisms enable the lighting system to deliver not just the needed amount of light,

but also offers the ability to tune the type of light to suit the activity and users in a particular space. Environmentally aware, decision-directed, multi-sensor networks and optimized light will

enhance not only the productivity of the built space, but also worker and group productivity, as well as increasing the health and well-being of individuals.

TSL4531 Features:

- Direct lux output
- Approximates the human eye's spectral response in diverse lighting conditions
- Three user-selectable integration times: 400 ms, 200 ms, and 100 ms
- Wide dynamic range: 3 lux to 220,000 lux
- Low active current: 110 μ A typical
- Power down mode: 2.2 μ A typical
- 16-bit digital output compatible with I²C interface
- Ultra-small 2mm x 2mm ChipLED package
- 2.5 V supply voltage with 1.8V logic interface
- Rejects 50 Hz/60 Hz lighting ripple

The TSL4531 ambient light sensor IC is available now in volume production.

www.austriamicrosystems.com

www.taosinc.com

(120304-VI)

RL78 Green Energy Challenge

Renesas' true Low Power MCU platform



By Mohammed Dogar (Germany)

In our Green Energy world many electronic designs are driven by requirements for reduced size, improved scalability, intelligent functionality and most importantly low power consumption.

The Renesas RL78 microcontroller (MCU) family is specifically designed to meet these demands by incorporating the highest peripheral integration, intelligent CPU architecture and advanced power-management capabilities to enable 'True Low Power Design'. In addition to excellent general low power characteristics RL78 MCUs incorporate special functions to minimise operating current. Major sections of the MCUs can be turned off, while key peripheral blocks of the device continue to function.

This smart low power operation is achieved with the unique 'Snooze Mode' capability. Snooze Mode dramatically reduces the power consumption of many typical MCU functions. The power savings are accomplished by allowing common data acquisition or data-transmission functions to operate without the need to wake up the CPU. This operational flexibility is a significant advantage over other low-power modes in which the CPU must remain active and assist with common peripheral functions.

In a system that periodically measures an analogue signal, the Snooze Mode enables an RL78/G13 MCU to achieve over 30% reduction in the system's average power dissipation compared to an implementation without this mode.

Besides Snooze Mode, RL78 MCUs have other important low-power characteristics that are valuable for power-constrained designs. Their wide operating range, from 1.6 V to 5.5 V, suits battery-based applications where the voltage (V_{cc}) drops over time as the battery gradually discharges.

RL78 MCU — reducing power consumption over 30%

In extreme applications some battery operated equipment must run off a battery for their entire operating lifetime, without any recharges whatsoever. Such designs require the lowest operating current possible. It is absolutely critical to turn-off functions in the system whenever they aren't needed and wake-up functions only

when they're required. The ability to wait in a very low power state until action is required and then wake up to take necessary action and do so while using as little current as possible is one that can dramatically extend useful lifetimes.

Renesas' RL78 MCUs are recommended solutions for embedded systems that mandate low-power operation requirements because they provide advanced power-management capabilities.

These functions allow the MCU to operate as follows:

- 1) run with exceptional power efficiency in the normal Run Mode;
- 2) disable CPU operation, saving power in Halt Mode (allowing fast CPU wake-up time);
- 3) disable more of the MCU functions in the Stop Mode to save the most power (at the expense of a longer CPU wake-up time);
- 4) Snooze Mode delivers even greater power savings.

Figure 1 shows an operational flow diagram for these three modes.

RL78 MCU — Snooze Mode operation

The Snooze Mode lets some peripheral functions wake up and execute simple operations while the rest of the MCU is stopped. This saves a significant amount of power compared to the Run or Halt Modes because in Snooze the CPU is off and only the peripherals that must operate are enabled.

Data reception from the synchronous serial port, the UART or a data conversion by the A/D converter can operate in the Snooze Mode by waking up the associated port, but not the CPU.

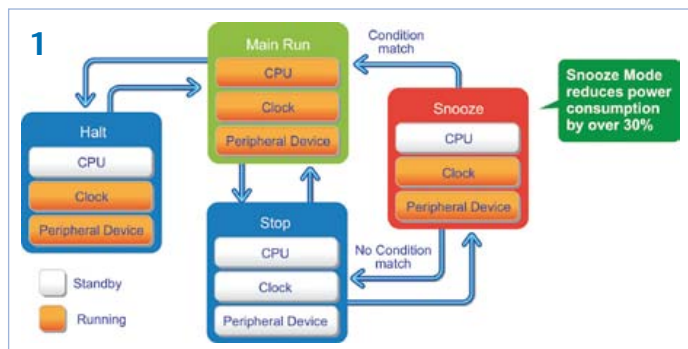
The A/D converter can 'wake up' when the RTC or the Interval Timer generates interrupt signals to start a conversion. Similarly, the synchronous serial port can 'wake-up' when the Serial Clock input pin edge is detected, and the UART can 'wake up' when an edge on the RxD input is detected.

After any data reception operation in Snooze Mode is completed, a 'match condition' is checked. If the condition is a match, then the



Mohammed "Mo" Dogar works for Renesas Europe as a product marketing manager, focused on promoting and selling microcontroller devices into major OEMs and distributors.

Mo's group defines and develops MCU product roadmaps and development support infrastructure for wide range of Industrial and Consumer electronics applications.



MCU exits the Snooze Mode and enters the Run Mode. If the condition isn't a match, operation returns to the Stop Mode. Thus, the CPU can be activated only when the data received requires action from the CPU. **Figure 2** illustrates Snooze Mode using the ADC triggered by timer.

For example, A/D conversion uses only 0.5 mA in Snooze Mode, rather than 5 mA in Run Mode, hence dramatic power consumption advantages are obtained.

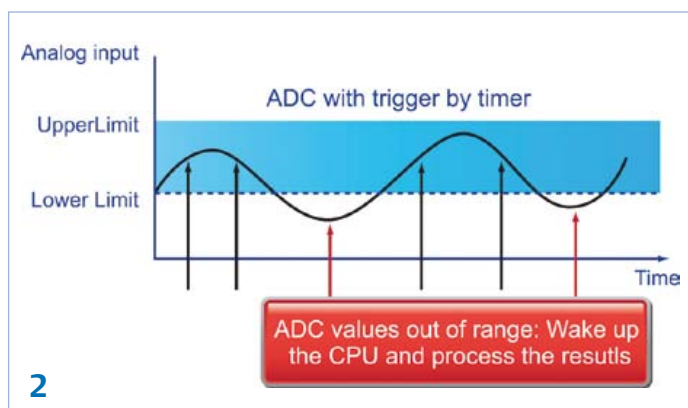
Thus, an A/D conversion can be performed in Snooze Mode using only 0.5 mA, 90% less than the 5 mA required to make a conversion in Run Mode.

Now it's your turn

We've discussed the ultra low power features of the RL78 MCUs, now what can you do with it? How will you use the energy saving features of the RL78 in your project for the RL78 Green Energy Design Challenge? Even more, how can you take these features into your everyday design and project pushing to green energy envelope to the next level and working to shape the future?

(120294)

www.circuitcellar.com/RenesasRL78Challenge

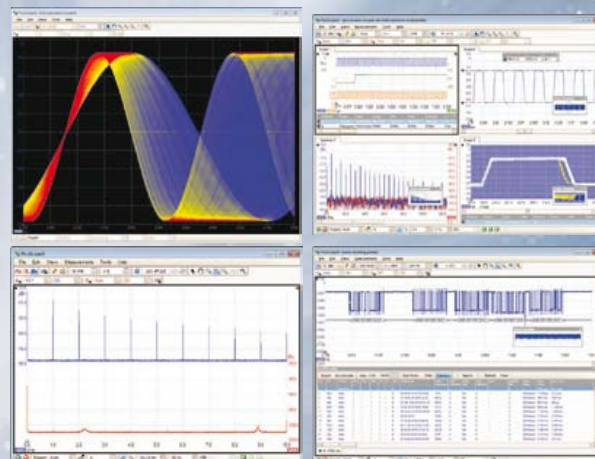


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Nixie Thermometer / Hygrometer

Tubes, sensors and a micro in a single design

By Hans Oppermann (Germany)

Measuring temperature and humidity with a modern sensor and displaying the values on a retro display — it's all described in this article.

A calibrated, 'digital' sensor provides data via its I²C interface to a microcontroller driving four Nixie tubes and automatically alternating between temperature and humidity, while providing a nice fading effect. It's a must-have!



When I first laid eyes on the cover of the January 2011 edition of Elektor magazine I was determined: I had to have a Nixie Tube Thermometer myself! Before getting started, I did some research on Nixie Tubes and was astounded by the sheer number of types available on the market. I stumbled upon a certain model — the IN-19A — that displayed a variety of physical units. While I had some experience using Sensirion SHT sensors and also on the lookout for a high

precision thermometer for use in my living room, I soon decided to develop my own circuit that would meet my demands, combining them of course with these fine, newly discovered Nixie tubes.

Hardware

The majority of the components were already pretty much predetermined by the Elektor Nixie Thermometer project. At the basic level this circuit consists of a micro-

controller, a sensor, a step-up converter based on an MC34063 and a Nixie driver IC consisting of the good old 74141. The circuit is shown in **Figure 1**. No SMDs, except for the sensor, are used in order to make construction as straightforward as possible. The power supply is very similar to the one used in the above mentioned article. An external 12–15 V DC power supply (power adapter) should be used to power the circuit via K1. Regulator IC6 generates a steady 5 V

Features

- Sensor: Sensirion SHT21 [1]
- Temperature range: 0 to 99 degrees Celsius in tenths of degrees
- Humidity range: 0 to 99 % in tenths of percents
- Power supply: AC power adaptor, 12 V to 15 V
- Current consumption: about 300 mA at 12 V
- Tubes: Russian IN14 and IN19A
- Microcontroller: Microchip PIC16F876-20/SP
- Firmware: C (MPLAB) (source and hex files available for free download from [2])

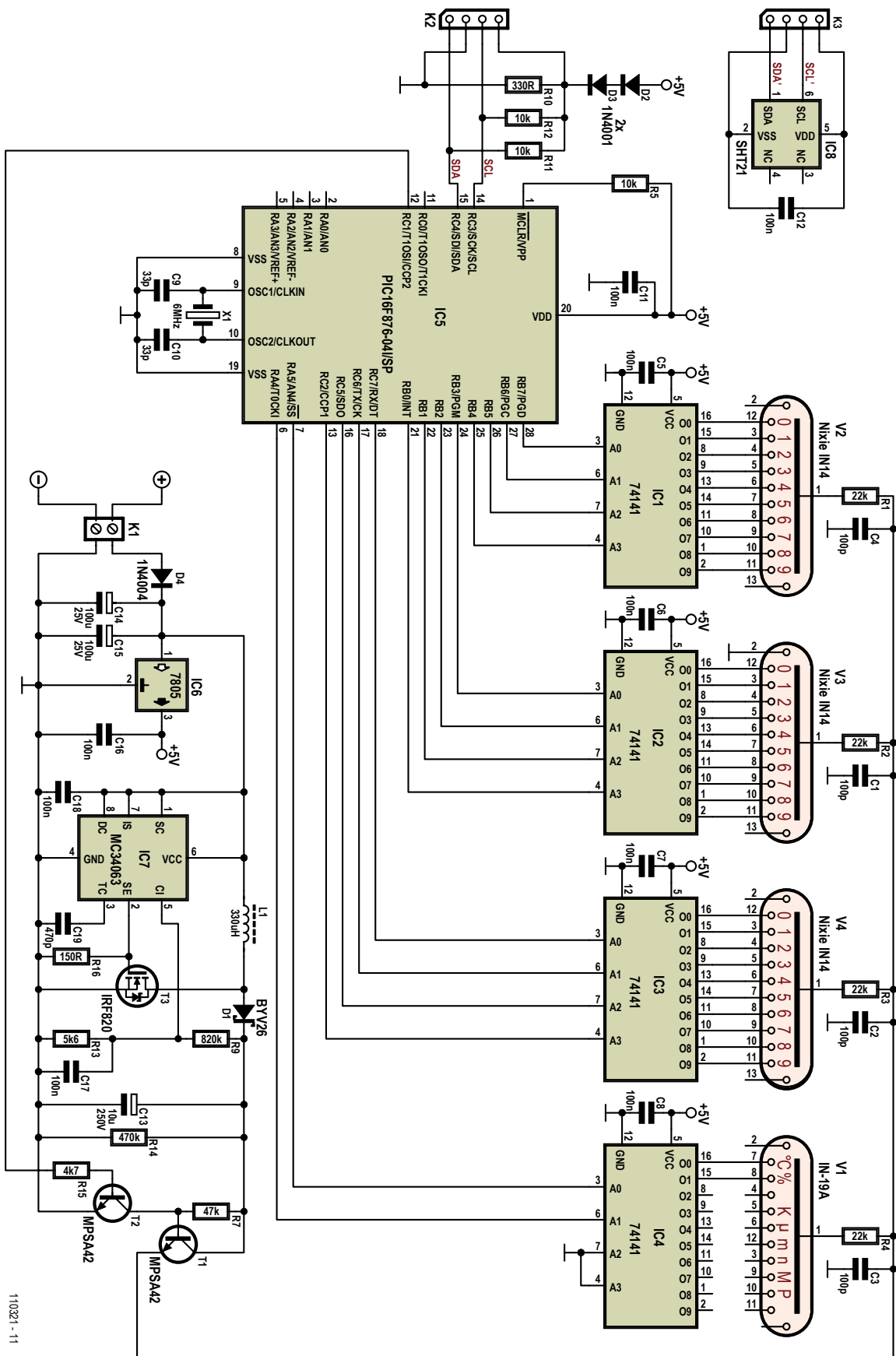


Figure 1. Clearly, the circuit resembles the earlier Nixie Thermometer project. There are a few differences, though.

COMPONENT LIST

Resistors

R1-R4 = 22kΩ
 R5, R11, R12 = 10kΩ
 R7 = 47kΩ
 R8 = not used
 R9 = 820kΩ
 R10 = 330Ω
 R13 = 5.6kΩ
 R14 = 470kΩ
 R15 = 4.7kΩ
 R16 = 150Ω

Capacitors

C1-C4 = 100pF 2000V, 10%, radial, 5mm pitch
 (Farnell #1141797)
 C5-C8, C11, C12, C16-C18 = 100nF 50V, 20%,
 pitch 5mm
 C9, C10 = 33pF 100V, 5%, 2.54mm pitch
 C13 = 10μF 250V, 20%, radial, 5mm pitch
 C14, C15 = 100μF 25V, 20%, radial, 2.5mm
 pitch
 C19 = 470pF, 100V, 10%, 5mm pitch

Inductors

L1 = 330μH 1A, 20%, axial, D×L = 11×32.5 mm
 (0.43"×1.28") max.

Semiconductors

D1 = BYV26
 D2-D4 = 1N4001
 IC1-IC4 = 74141 or K155ID1 (K155ID1)
 IC5 = PIC16F876-20/SP
 IC6 = 7805
 IC7 = MC34063
 IC8 = SHT21 I²C humidity and temperature
 sensor [1] (Farnell #1855468)
 T1, T2 = MPSA42

T3 = IRF820

Miscellaneous

X1 = 6MHz quartz crystal
 V1 = IN-19A, Nixie Tube (symbols)
 V2-V4 = IN-14, Nixie Tube (numeric)

K1 = 2-way PCB terminal block, 5mm pitch
 PCB # 110321-1, available via www.elektor.com/110321

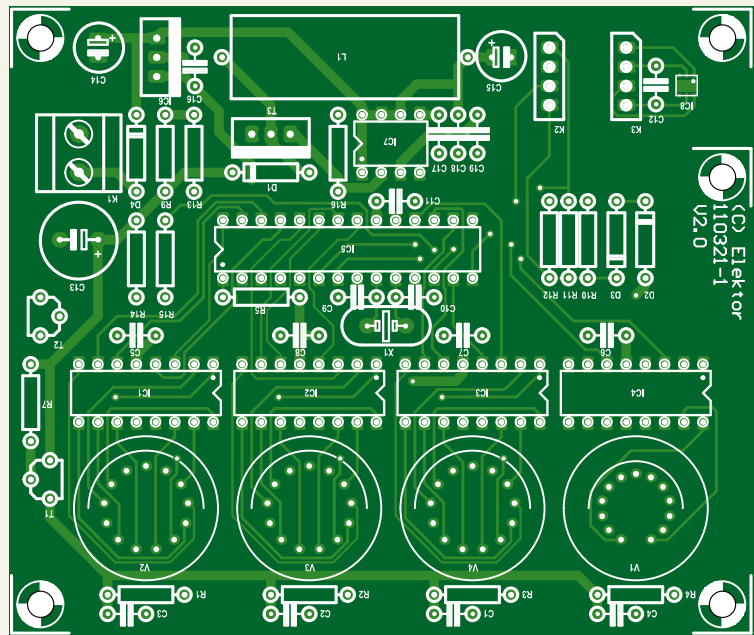


Figure 2. The PCB can be ordered via the Elektor Shop or an artwork PDF can be downloaded from the project web page [2].

for powering the microcontroller and the 74141 decoder ICs. The high voltage supply required for the Nixie tubes is generated with IC7. This PWM controller switches MOSFET T3 in order to step up the voltage, using inductor L1 and Schottky diode D1. The output voltage is given by

$$V_o = V_{ref} \times R9 / R13$$

which, with the given values results in

$$V_o = 1.25 \text{ V} \times 820 \text{ k}\Omega / 5.6 \text{ k}\Omega = 183 \text{ V.}$$

R1-4 take the high voltage supply to the anodes of the IN-14 tubes, giving an operating voltage of around 143 V. With this relatively high voltage the tube filaments will light up brightly. If less brightness is needed, R9 may be replaced by 680 kΩ, resulting in a voltage of about 152 V at the supply output.

The high voltage supply line to the Nixie tubes can be controlled by the microcontroller via T1 and T2. Reducing the duty

cycle of the PWM signal applied to the base of T2 results in a higher voltage at the base of T1, which in turn results in a higher voltage supplied to the Nixie tubes and thus a brighter lighting display. This way the switching between humidity and temperature display can be done quite nicely by slowly increasing the PWM duty cycle, resulting in dimming of the filaments and, after applying the new settings for the Nixie drivers, slowly decreasing the duty cycle of the PWM signal again, increasing the brightness of the newly selected filaments.

The sensor used for measuring temperature and humidity differs from the one used in the earlier Elektor Nixie Tube Thermometer. In this circuit a Sensirion SHT21 [1] is used. This calibrated sensor emits its data digitally via an I²C interface. It requires a 3.3 V supply, which is generated using the voltage drop across two diodes (D2, D3). Connecting SCL and SDA with a pullup resistor to 3.3 V on the sensor side prevents the upper voltage limits to be exceeded by the

PIC powered at 5 V. The Low level of SDA and SCL is 'generated' by tying the pins to ground, while the High level signal is 'generated' by floating the PIC output pins. Pull-ups R11 and R12 then define the SDA and SCL levels as High (3.3 V).

At the core we find the PIC16 microcontroller. Its 6 MHz clock is generated by external quartz crystal X1. Since this circuit functions stand alone, it requires no controls or other interfaces. The software runs by itself and alternates between the displayed measured values automatically.

Software

Designed in C using the MPLAB IDE, the software is quite straightforward. Temperature and humidity are periodically read out from the SHT21 sensor via its digital I²C interface and received at the corresponding ports of the PIC. Sample codes for interfacing the sensor are freely available in C from the Download Center on the Sensirion website, which makes it very easy to implement these functions in our firmware.

For clarity's sake, the output to the decoders is generated using a lookup table. Since there is no 'F' filament in the IN-19A, a Fahrenheit indication option is not implemented.

Construction

The PCB (see **Figure 2**) can be ordered via the project web page [2] or a .pdf with the layout can be downloaded from the same page in case you want to etch the board yourself.

The sensor should be positioned a minimum of about 15 cm (5 inches) away from the circuit. The heating of the components, especially the 74141 decoder ICs, may impair an accurate temperature measurement. The sensor is connected to the controller board

using a four-wire cable and SIL headers (K2, K3). In one corner of the PCB there is a separate section for mounting the sensor, C12 and connector K3. This section can be cut off and located away from the main board. Mounting the components on the PCB is a breeze. As usual, start with the low profile ones like resistors and place the ones with the tallest ones last. Guiding the leads of the Nixie tubes through the PCB might try your patience. However, there is a trick to this, as described in last month's E-labs Inside section [3]: cut the leads in a 'staircase' fashion, each one a little shorter than the one next to it. Now they can be easily guided through the PCB holes one at a time. Pay close attention to its orientation. An arrow on the bottom of the tube indicates pin 1 (see also the datasheet).

An electrically insulated enclosure should be used, since the circuit generates high voltages. It's important that no metal parts are exposed. Nylon screws and insulating sockets should also be used or other insulating measures should be taken.

Nixie tubes

Nixie tubes and 74141 decoder ICs are readily available on Ebay. Especially from the former USSR several large (ex military?) quantities are offered at affordable prices. Production of tubes lasted well into the 1980s; some say because of technological backwardness, others argue the tube's superior immunity to EMP made it the best choice for active components.

In this design especially the IN-19A is remarkable. This tube is especially con-

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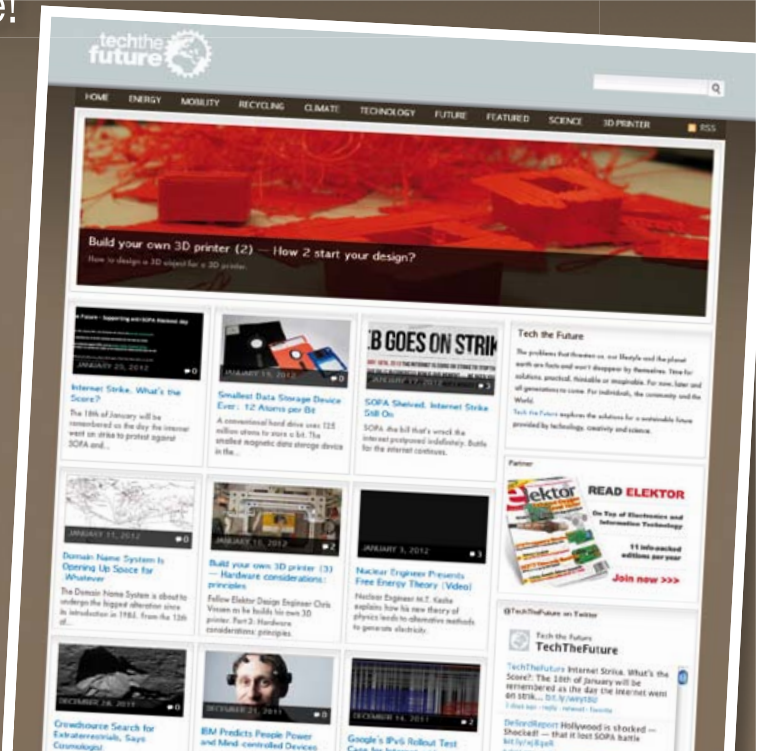
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structed to display symbols of units. Our circuit only uses two of them: ‘%’ and ‘°C’. Note the suffix ‘A’! See also the head illustration. For those having trouble reading Cyrillic characters, here’s the ‘translation’ of the table:

IN-19A	IN-19B	IN-19V
%	S	–
M	F	A/B
P	H	~
m	V	Π
K	T	<
n	A	>
μ	Hz	dB
°C	Ω	+

Pay close attention: the Cyrillic ‘B’ translates to our ‘V’. The ‘B’ would be pronounced as the ‘B’ of our Western character set.

Nice to know: notice how the ‘2’ and ‘5’ filaments in the IN-14 number tubes are actually the same, only one is upside down. Budget cuts or just clever engineering?

To round up

Once assembled and fully connected, the circuit should work right away. No calibrations or other setup procedures are required. The accuracy tolerance of the sensor is ± 0.3 °C typical (between 5 and 60 °C), while the resolution can reach 0.01 °C. Consequently, with a displayed temperature of 25.0 °C the real temperature can be between 24.7 and 25.3 °C.

A side note on the sensor: the humidity measured by the sensor can be quite off the mark. That’s a little strange for a calibrated sensor, don’t you think? Perhaps it has something to do with mounting the sensor on the main PCB, as was done with our prototype. A logging circuit published

last year in Elektor also showed these symptoms. Some investigation may be in order here.

At the time of writing the author is working on a wireless solution where the sensor is fitted in a separate enclosure together with the PIC and an RFM-12.

A short impression of the circuit and the fading effect can be found on the Elektor YouTube channel [4].

(110321)

About the author

Hans Oppermann was educated as a radio and television engineer between 1963 and 1966, followed by a degree in Physical Engineering. Until his retirement in 2006, he worked as a Software Engineer with several software developing companies. He stayed loyal to his hobby and kept designing electronic circuits throughout his career, often related to electric model airplanes. Since the arrival of microcontrollers, he built one into almost all of his circuits — mostly resorting to the PIC variety — time and again staggered by the absence of the need for complicated wiring. Among others, he also developed a weather station with long-term data logging and wireless transmission, a measurement circuit for domestic power usage, also with a wireless read out option, an infra-red readout of long-term values for PDA and a twilight switch for outdoor lighting.

His preferred programming language is tcl/TK, which he also uses on his PDA to bypass operating elements on electronic devices, such as the GUI on a PDA.

Internet Links

- [1] www.sensirion.com/sht21
- [2] www.elektor.com/110321
- [3] www.elektor.com/120229
- [4] www.youtube.com/ElektorIM

Elektor Products & Resources

- Source code and hex files
 - Printed circuit board
- Available via www.elektor.com/110321.



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Participation in Weekly Challenges and receipt of partner prizes is not a factor in selecting winners for the Grand Cash Prize from Renesas. Remember, a complete Project Entry is your Abstract, Complete Documentation, Photos and all supporting Source Code, zipped in one comprehensive file, labeled with your unique Project Registration Number, and uploaded to the contest Dropbox. See website for complete rules and details. Void where prohibited by law.

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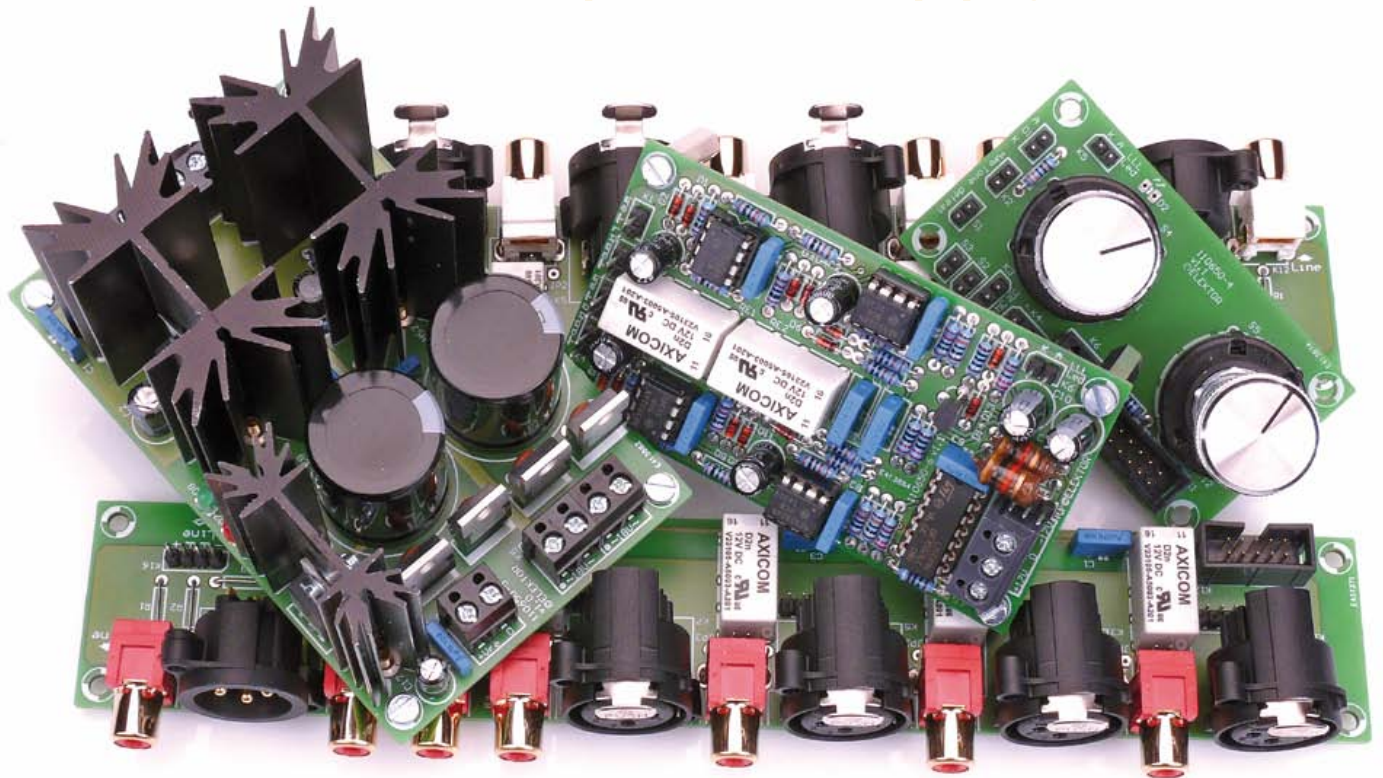
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Preamplifier 2012 (3)

Part 3: level indicator, source selector, power supply



By Douglas Self (UK)

This month we close off the discussions of the individual boards that make up the preamplifier, both in terms of theory of operation and construction.

The Log-Law Level LED (LLLL) stage

The Log Law Level LED, or LLLL, is to the best of my knowledge, a new idea. A normal single-LED level indicator is driven by a comparator, and typically goes from fully-off to fully-on with less than a 2 dB change in level when fed with music (not sinewaves). It therefore does not give much information. The LLLL, on the other hand, incorporates a simple logarithmic converter so the range from LED-always-off to LED-always-on is extended to 10 dB. The preamplifier internal level is correct when the LED is on about 50% of the time. This gives a much better indication as you can judge the level

approximately from the on/off ratio. Referring to the circuit diagram in **Figure 1**, IC1A with R1, R2, D1, D2 is a precision half-wave rectifier circuit. Its output when combined with the feed through R3 provides a full-wave rectified signal to IC1B; this is another precision rectifier that establishes the peak level of the signal on C2. This is buffered by IC2A to prevent loading by the next stage, and the peak voltage is applied to the very simple log-law converter IC2B. For low level signals the gain is set to unity by R6 and R7. As the input voltage increases, first D5 begins to conduct, reducing the gain of the stage by increased negative feedback through R8. At a higher

voltage set by divider R9 and R10, D6 also conducts, reducing the gain further by negative feedback through R9. This simple circuit clearly gives only a very approximate version of a log law but it transforms the operation of the indicator.

The processed voltage is applied to comparator IC5A, and if the threshold set by R21, R22 is exceeded the open-collector output of IC5A goes Low and the output of IC5B, which simply acts as a logical inverter, goes High, removing the short across the LED connected to pinheader K6 and allowing it to be powered by current source T1. There are two channels for stereo operation and

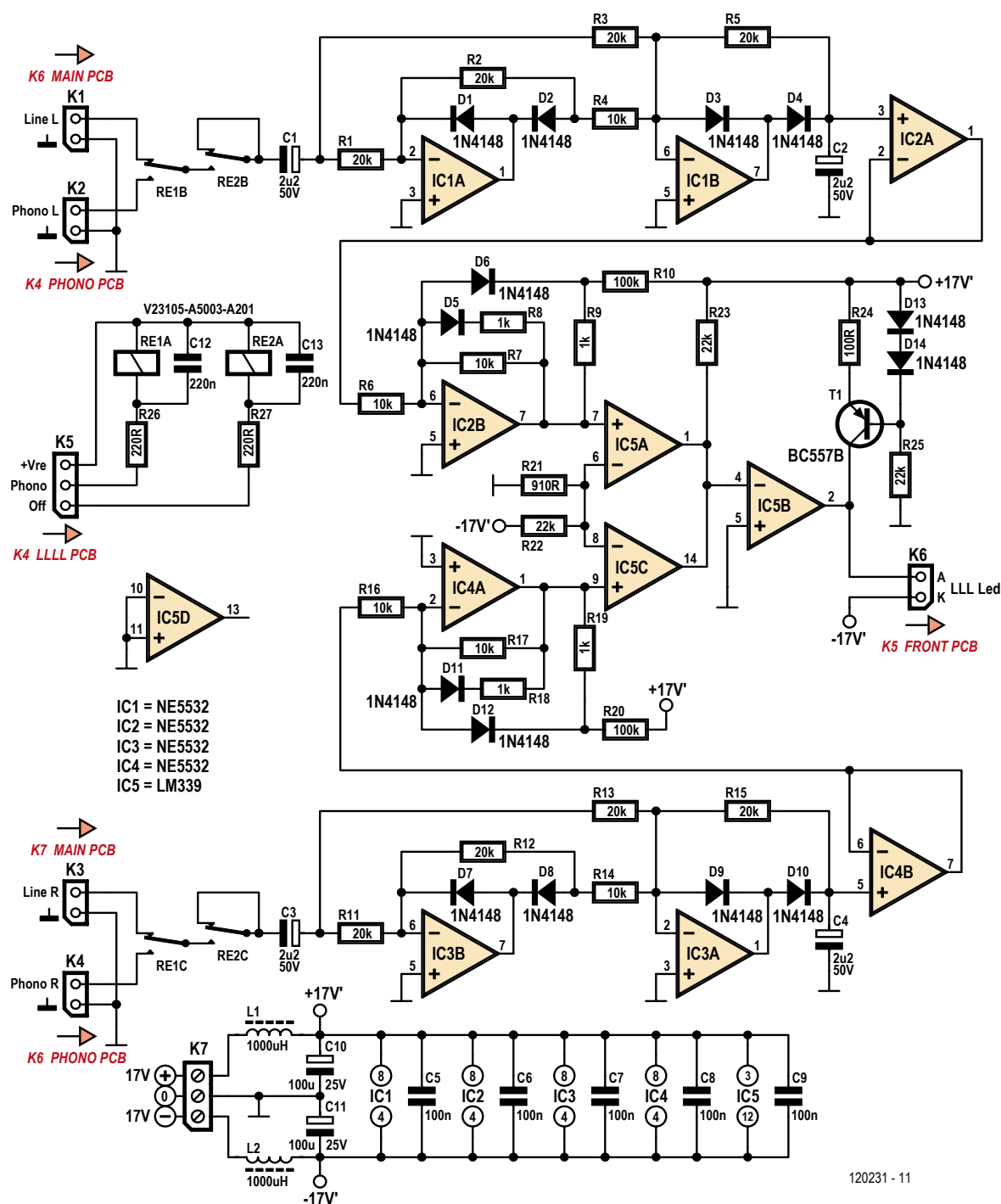


Figure 1. Schematic of the Log-Law Level LED (LLLL) board.

the outputs of comparators IC5A and IC5C are wire-OR'd together to pull-up resistor R23 so that a signal on either channel will make the LED illuminate. IC5D is not used. The LLLL can be switched to read either the phono input directly (so the switched-gain stage can be set up correctly) or the signal after the input select relays and balanced

line input stage, where it can be used to check the incoming level of any input. This switching is done by relay contacts RE1B, RE1C. Series relay contacts RE2B, RE2C allow the LLLL to be disabled when its job is done and the flickering LED may become irritating.

The LLLL is built on circuit board no.

110650-6 shown in **Figure 2**. It contains through-hole components only, hence nothing should hinder you from producing a working board straight off if you are careful about placing and soldering the parts. The same applies to the other three (four) boards discussed below. The finished LLLL board is pictured in **Figure 3**.

COMPONENT LIST

LLLL board (# 110650-6)

Resistors

(0.25W, 1%)

R1,R2,R3,R5,R11,R12,R13,R15 = 20k Ω

R4,R6,R7,R14,R16,R17 = 10k Ω

R8,R9,R18,R19 = 1k Ω

R10,R20 = 100k Ω

R21 = 910 Ω

R22,R23,R25 = 22k Ω

R24 = 100 Ω

R26,R27 = 220 Ω

Capacitors

C1-C4 = 2.2 μ F 20% 100V, diam. 6.3mm,

2.5mm pitch

C5-C9 = 100nF 10% 100V, 7.5mm pitch

C10,C11 = 100 μ F 20% 25V, diam. 6.3mm,

2.5mm pitch

C12,C13 = 220nF 10%, 100V, 7.5mm pitch

Inductors

L1,L2 = 1mH 3.6 Ω 370mA, axial

Semiconductors

D1-D14 = 1N4148

T1 = BC557B

IC1-IC4 = NE5532

IC5 = LM339

Miscellaneous

K1-K4,K6 = 2-pin pinheader, 0.1" pitch (2.54mm)

Socket headers for K1-K4,K6

K5 = 3-pin pinheader, 0.1" pitch (2.54mm)

Socket header for K5

K7 = 3-way PCB terminal block, 5mm pitch

RE1,RE2 = V23105-A5003-A201, 12V/960 Ω ,

230V/3A, DPDT

PCB # 110650-6 (www.elektorpcbservice.com)

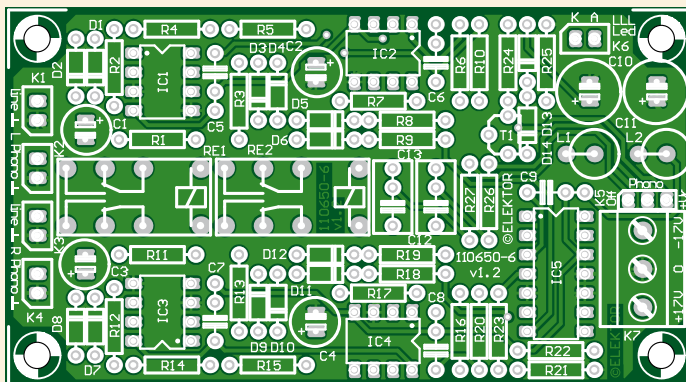


Figure 2. The combined metering and driver circuitry of the Log-Law Level LED indicator is built on this board. Board available through www.elektorpcbservice.com.

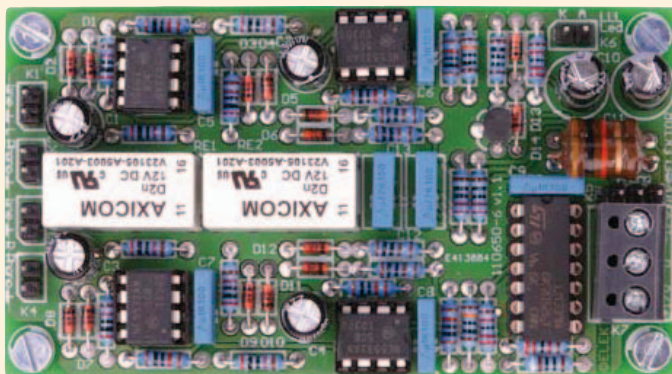


Figure 3. Prototype of the LLLL board built by Elektor Labs.

The input PCBs

The input circuit boards (one per channel) carry the input and output connectors plus the relays that select which input is in use. Their circuit diagram appears in **Figure 4**. The four line-level inputs can work in either unbalanced or balanced mode, though of course balanced mode is strongly recommended because it rejects electrical noise on the ground paths. Bear in mind this is true *even if the source is unbalanced*. In this case the cold (phase-inverted) balanced input must be connected to ground at the source end of the cable — a 3-way cable is still required. There is therefore no technical reason to provide RCA connectors but they are included for convenience. If they are to be used the jumpers JP1–JP4 must be installed.

For Input 1, relay contacts RE1B, RE1C connect to the preamplifier input when relay coil RE1A is energised, and the signal goes to the main preamplifier board via connector K15.

Facilities are also provided for using the XLR inputs in unbalanced mode; in this case the jumper S1 is set so that RE1B connects to ground rather than pin 3 of the XLR. The same applies to Input 2 and Input 3. However, if you have spent the money for an XLR you really should make proper use of it by employing balanced mode.

Input 4 is the phono input if the phono facility is included in the preamplifier. Input 4 is used for either MM or MC mode, as this selection is made on the phono PCB discussed in part 2. In this case K7 and K8 are not fitted. If the phono PCB is not used Input 4 can be used as another Line input, with K7 and K8 fitted. In this case there is no connection to K13.

There is no facility for using the MC and MM cartridge inputs in balanced mode so only RCA connectors are provided for these inputs.

This circuit is constructed on circuit board no. 110650-3 pictured in **Figure 5**; the assembled board appears in **Figure 6**.

The front panel PCB

The front panel board of which the schematic is shown in **Figure 7**, carries the input select switch, the LLLL source select switch, the three mode switches, and the power

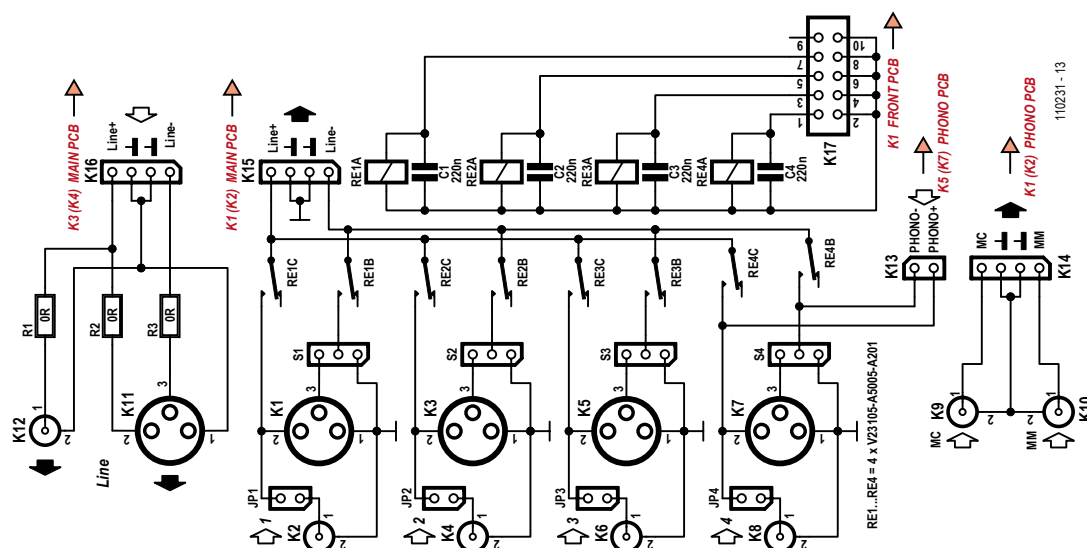


Figure 4. Circuit diagram of the input section of the preamplifier.

COMPONENT LIST

Input board (#110650-3)

Resistors

R1, R2 = 0Ω

Capacitors

C1-C4 = 220nF 10% 100V, 7.5mm lead pitch

Miscellaneous

K1, K3, K5, K7 = XLR socket, PCB mount, horizontal, 3-way

K11 = XLR plug, PCB mount, horizontal, 3-way
 K2, K4, K6, K8-K10, K12 = RCA/Phono socket, PCB mount, Pro Signal type PSG01545 (red) (R) or PSG01546 (white) (L)
 K13, JP1-JP4 = 2-pin pinheader, 0.1" pitch (2.54mm)
 Socket header for K13
 K14, K15, K16 = 4-pin pinheader, 0.1" pitch (2.54mm)
 Socket headers for K14, K15, K16
 K17 = 10-way boxheader, straight, 0.1" pitch (2.54mm)

S1-S4 = 3-pin pinheader, 0.1" pitch (2.54mm)
 Jumpers for S1-S4, JP1-JP4
 RE1-RE4 = V23105-A5003-A201, 12V/960Ω, 230V/3A, DPDT
 PCB # 110650-3 (www.elektorpcbservice.com); 2 pcs required

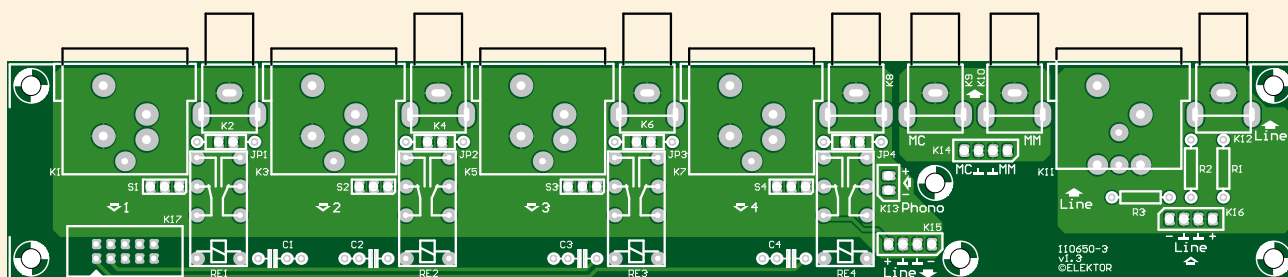


Figure 5. The preamplifier's input board (here at 75% of its real size). Two of these are required for stereo operation. Board available through www.elektorpcbservice.com.

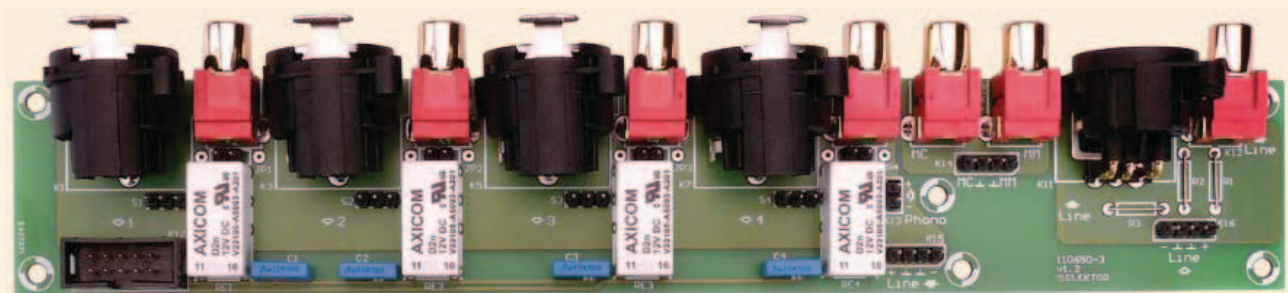


Figure 6. Fully assembled Input board.

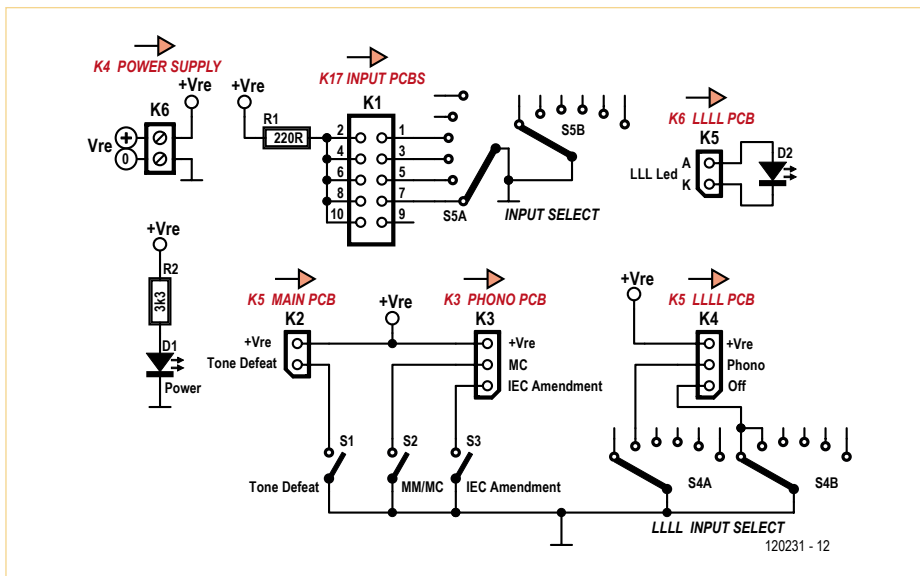


Figure 7. This sub circuit of switches, LEDs, resistors and connectors forms a separate board intended for fitting to the inside of the preamplifier front panel.

and LLL LEDs.

S5A is the input select switch, controlling the relays on the input boards. Only the first four positions are used, the other two being

blocked off by a mechanical stop. S5B is not used. The switching between MM/MC and Line input is done by a separate switch S2 on the front panel board.

S4A and S4B control the operation of the LLLL indicator. In the first position the LLLL is fed from after the input select and balanced input stage and can be used to check any input. In the second position it is fed from the phono stage only, whichever input is selected. The third position removes the signal fed to the LLLL and so disables it. Only the first three positions of the switch are used (Line—Phono—Off) and the other three are blocked off by a mechanical stop. Switch S1 controls the tone-control defeat relay. When S1 is closed the tone-control is bypassed completely.

Switch S2 selects between moving-magnet (MM) and moving-coil (MC) operation, using relay contacts RE1B, RE1C on the phono PCB. When S2 is closed the MC input is active.

S3 selects the IEC amendment, which is a largely unwanted extra roll-off at 20 Hz that

COMPONENT LIST

Front panel board (# 110650-4)

Resistors

(0.25W, 1%)
R1 = 220Ω
R2 = 3.3kΩ

Semiconductors

D1 = LED, green, 3mm, through hole
D2 = LED, red, 3mm, through hole

Miscellaneous

K1 = 10-way boxheader, straight, 0.1" pitch (2.54mm)
K2, K5, D1, S1-S3 = 2-pin pinheader, 0.1" pitch (2.54mm)
Socket headers for K2, K5, D1, S1-S3
K3, K4 = 3-pin pinheader, 0.1" pitch (2.54mm)
Socket headers for K3, K4
K6 = 2-way PCB terminal block, 5mm pitch
S1, S2, S3 = switch, SPDT (On-On)
S4, S5 = 2-pole, 6-position rotary switch, PCB mount, e.g. Lorlin type CK1050
PCB # 110650-4
(www.elektorpcbservice.com)

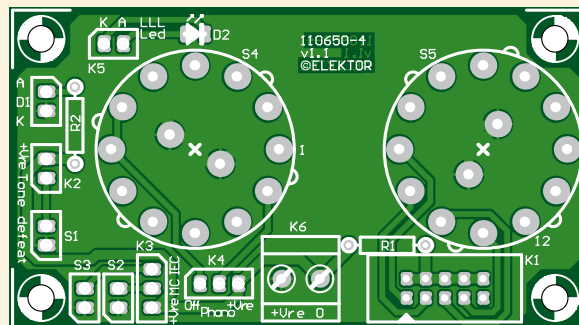


Figure 8. The front panel circuit board.
Board available through www.elektorpcbservice.com.

Figure 9. The Front Panel board, ready for use.

was later added to the RIAA spec. When S3 is closed the IEC amendment is applied. The small board no. 110650-4 for securing to the front panel of your preamplifier case is pictured in **Figure 8**, along with the Component List. Check **Figure 9** for the assembled board.

The power supply PCB

The power supply is fairly conventional as the preamplifier does not require ultra-low noise on the supply rails to give its best performance. Referring to **Figure 10**, a centre-tapped 18–0–18 V power transformer, a bridge rectifier D3–D6 and reservoir capacitors C8, C10 produce the unregulated supply voltages. Snubbing capacitors C14–C17 prevent RF being generated by the rectifier diodes. LEDs D7 and D8 are mounted on the PCB and indicate that the unit is powered and both unregulated supplies are present. The ± 17 V supplies for the opamps are generated by regulators IC1 and IC2. The networks R1, R2 and R3, R4 set the voltage required while C5 and C6 improve the ripple performance of the regulators. D1 and D2 prevent the stored charge on C5 and C6 damaging the regulators if the output is short-circuited. Capacitors C1–C4 reduce the output impedance of the supply at high frequencies.

A separate +15 V regulator IC3 is used to power the relays. This is powered from the unregulated positive supply that also feeds the +17 V regulator. Note that the audio ground and the relay ground must be connected together at one point only, right back at the power supply; otherwise relay currents flowing in the audio ground will cause unpleasant clicking noises in the preamp output.

Number 110650-5 is the last board you'll be building to construct the Preamplifier 2012; it's shown in **Figures 11** (PCB only) and **12** (assembled board).

Wiring

Comprising a total of seven boards, the Preamplifier 2012 is quite an intricate job to wire up. For your convenience the connectors ('Kx') in this month's schematics have been given what/where/to labels. Most of the board interconnections consist of short runs of 2, 3 or 4 light duty, flexible

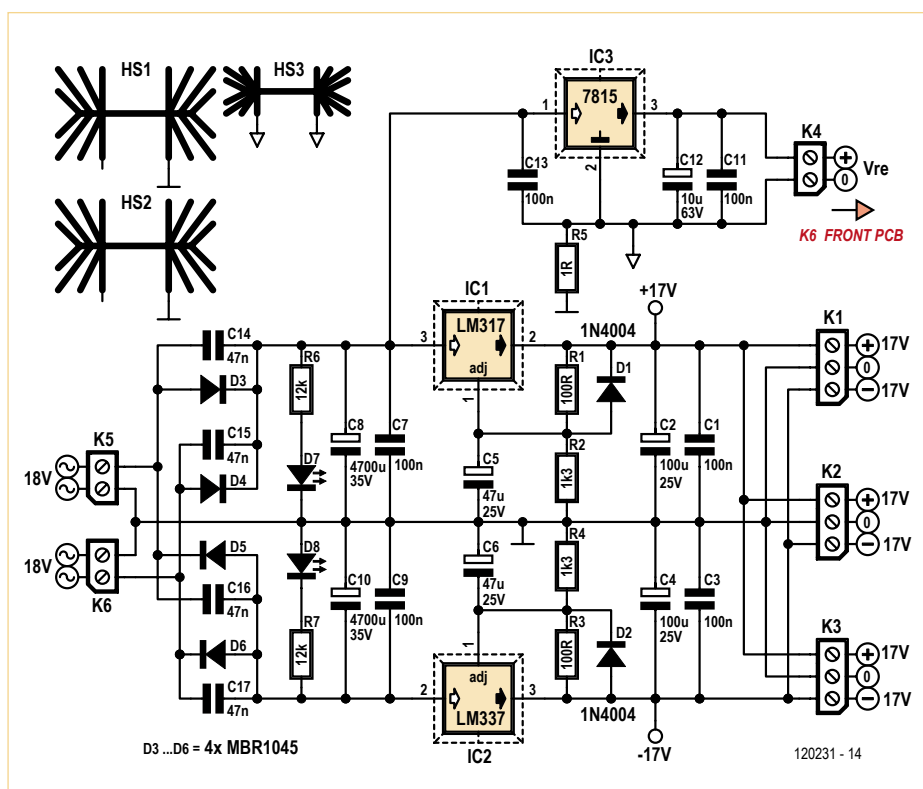


Figure 10. The circuit diagram of the power supply holds common-or-garden components hence few surprises. Note that the relays have their own 15 V voltage regulator.

COMPONENT LIST

Power supply board (#110650-5)

Resistors

(0.25W, 1%)
 R1,R3 = 100Ω
 R2,R4 = 1.3kΩ
 R5 = 1Ω
 R6,R7 = 12kΩ

Capacitors

C1,C3,C7,C9,C11,C13 = 100nF 10% 100V,
 7.5mm pitch
 C2,C4 = 100μF 20% 25V, 6.3mm diam., 2.5
 mm pitch
 C5,C6 = 47μF 20%, 25V, 6.3 mm diam., 2.5
 mm pitch
 C8,C10 = 4700μF 20% 35V, 22mm diam.,
 10mm pitch
 C12 = 10μF 20% 63V, 6.3mm diam., 2.5mm
 pitch
 C14-C17 = 47nF 50V, ceramic, 5mm pitch

Semiconductors

D1,D2 = 1N4004
 D3-D6 = MBR1045
 D7 = LED, red, 3mm, through hole
 D8 = LED, green, 3mm, through hole
 IC1 = LM317
 IC2 = LM337
 IC3 = 7815

Miscellaneous

K1,K2,K3 = 3-way PCB terminal block, 5mm
 pitch
 K4,K5,K6 = 2-way PCB terminal block, 5mm
 pitch
 HS1,HS2 = heatsink, 50.8 mm, Fischer Elek-
 tronik type SK 129 50,8 STS
 HS3 = heatsink, 50.8 mm, Fischer Elektronik
 type SK 104 50,8 STS
 PCB # 110650-5 (www.elektorpcbservice.
 com)
 Not on PCB:
 Tr1 = AC power transformer, 115/230V prima-
 ry, 2x18V/50VA secondary, e.g. Multicomp #
 MCTA050/18, Farnell (Newark) # 9530380
 F1 (230VAC) = fuse, 0.315A antisurge,
 5x20mm, panel mount
 F1 (115VAC) = fuse, 0.63A antisurge,
 5x20mm, panel mount
 S1 = 115/230V AC line voltage selector, e.g.
 Arcoelectric Switches type T22205BAAC
 S2 = AC power switch

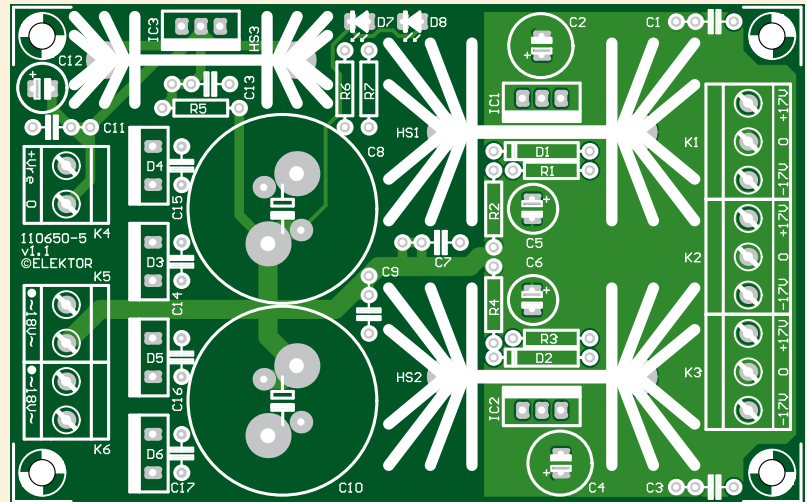


Figure 11. The power supply board.
 Board available through www.elektorpcbservice.com.

Figure 12. Preamplifier PSU board assembled by Elektor Labs.

wires of different colours (agree on black for ground though) twisted together and their ends soldered to the socket for plugging on the pinheader. Look at the symbol with the mating pinheader on the PCB to identify the bevelled edge, this will help you get the pin-to-pin connections right.

The 10-way connection between the front panel PCB and the input PCB is the only one requiring a length of flatcable (a.k.a. ribbon cable) with IDC sockets pressed on at the ends.

All wiring and components 'ahead of' and including power transformer Tr1 is at AC powerline potential hence should comply with safety regulations and recommendations in place for electrical safety. When in doubt, ask for help or advice from a qualified electrician.

At the time of writing the Preamplifier 2012 is fully wired up on the audio test bench at Elektor House, but not yet fitted in a case. The two input boards are mounted like a

sandwich using four PCB pillars. Depending on your response to the project we may do a final article later this year on installing the boards in a high quality enclosure. For now we leave that part of the project to you, as well as enjoying the superb sound quality of the Preamplifier 2012.

(120231)



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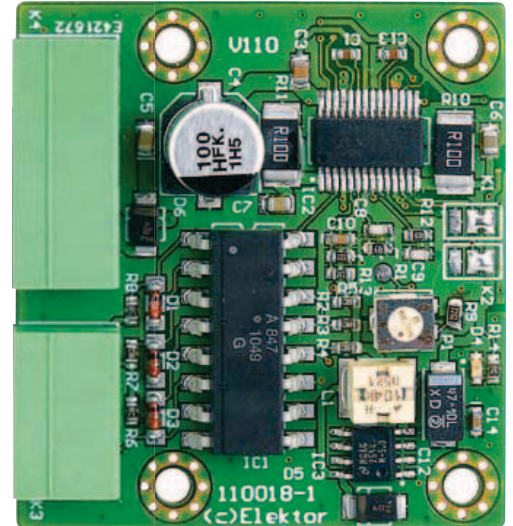
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Flexible Stepper Motor Driver

With electrically isolated interface

By Chris Vossen (Elektor Labs)

To enable the control of a stepper motor from, say, a parallel port of a PC, Elektor Labs have designed a compact driver PCB using the A3979 chip made by Allegro Microsystems. This chip has been specifically designed to control bipolar stepper motors in full-, half-, quarter- and sixteenth-step modes at currents of up to 2.5 A. The circuit is provided with optocouplers for electrical separation between the control inputs and the driver module.



Stepper motors are used in many mechatronics projects to implement some kind of motion. Applications such as robots, scanners, milling machines and 3D printers come to mind. There is often the desire to keep the accompanying electronics as simple as possible. In particular with hobby projects, the legacy Centronics port of a PC is still frequently used to control a few motors by way of power drivers.

For all those enthusiasts unable or unwilling to develop such a driver themselves, the guys at Elektor Labs have developed a universal board based on a special stepper motor driver IC and featuring full electrical isolation for the control signals. The supply voltage for the electronics is derived from the stepper motor's power supply using a small switch-mode power supply regulator, which ensures that the power dissipation is kept to a minimum.

The A3979

Allegro Microsystems' type A3979 is a so-called microstepping motor driver with integrated DMOS bridge and level shifter. This tiny IC (it measures only 6.5 x 10 mm

in size) can control stepper motors in full-, half-, quarter- and sixteenth-step modes with the aid of an integrated PWM controller. The internal FET bridge can supply a maximum current of 2.5 A at voltages up to 35 V. Thanks to the built-in 'translator' all manner of controlling a stepper motor with this IC is easy. After establishing the mode in which the motor is to be controlled, using inputs MS1 and MS2, a pulse at the STEP input is sufficient to make the attached motor rotate a full-step, half-step, etc. **Figure 1** shows the block diagram of the A3979, together with the necessary external components. The datasheet for the A3979 is available from [1].

Apart from the selection of a few of these external components, which we will return to shortly, there are very few things you need to consider. There are only three signals that need to be supplied for the control of the motor: step pulses, direction signal and enable signal.

Optical drive

In the complete schematic shown in **Figure 2** you can see that the A3979 is con-

nected according to the design already encountered in the block diagram. The windings of the stepper motor and the power supply voltage for the motor are connected to connector K4. The inputs MS1 and MS2, which are used to set the size of the microsteps of the motor, are connected to K1 and K2 in the schematic. In reality these 'connectors' are solder pads on the circuit board. The user can decide with two drops of solder across the appropriate pads which type of microsteps will be used. **Table 1** shows the different options that are available.

To allow as much electrical separation as possible between the controlling part (PC or a microcontroller board) and driver board, a four-way optocoupler is added in the form of an ACPL-847 made by Avago Technologies (IC1). When one of the inputs DIR, STEP or ENABLE is set to a Low level, the corresponding LED in the optocoupler will turn on and as a consequence the accompanying transistor will conduct. When changing the level at the DIR input the direction of rotation of the attached motor will change. With every rising edge at the STEP input the

Technical characteristics

- Suitable for most small bipolar stepper motors
- Integrated DMOS-bridges, maximum voltage/current: 30 V / 2.5 A
- Default current limit: 1.5 A
- Electrically isolated control lines using optocouplers
- Full-, half-, quarter- and sixteenth-step mode settable using solder bridges
- PWM control for minimal dissipation
- Built-in translator for controlling the motor
- Built-in blanking function for the DMOS bridges
- Various protection features built in (current and temperature, among others)

motor will perform one microstep. Finally, the motor driver is activated when the ENA-BLE signal is set to a Low level. The A3979 checks this level at every rising edge of the STEP input.

The driver circuit is completed with a small switching power supply, which is designed around an LM2594M-5.0. This step-down regulator derives a regulated 5 V rail from the motor supply voltage. The input voltage can be between 5 V and 30 V. LED D4 functions as the power-on indicator.

Component sizing

Parts R10 and R11 are the current sensing resistors for the two motor windings. They define the maximum current that is permitted to flow through the stepper motor coils. These resistors must have a very small self inductance. Any additional inductance in the measuring resistor will effectively appear in series with the winding of the motor. This increases the reactance (AC resistance) of the total circuit and results in a measuring error of the pulsewidth modulated signal.

According to the datasheet, R_{sense} has to satisfy the condition

$$R_{sense} < 0.5 / I_{trip}$$

where I_{trip} is the maximum permissible current for each coil in the motor. Here we set this to 1.5 A, which is an excellent value for the commonly used Nema-17 type of motors. When we enter this value into the formula we arrive at a value for R_{sense} of $< 0.33 \Omega$.

The datasheet for the A3979 gives a second requirement that needs to be satisfied: V_{ref} has to be equal to, or less than, 4 V. This voltage is determined by using the formula

$$V_{ref} = 8 \times I_{trip} \times R_{sense} \leq 4 \text{ V.}$$

Here a value of 1.5 A was chosen for I_{trip} , and a resistance of 0.1Ω for R_{sense} . This results in a maximum V_{ref} of 1.2 V. The motor current through each sense resistor results in a relatively high power dissipation. This power dissipation amounts to

$$P = I^2 \times R_{sense} = 0.225 \text{ W.}$$

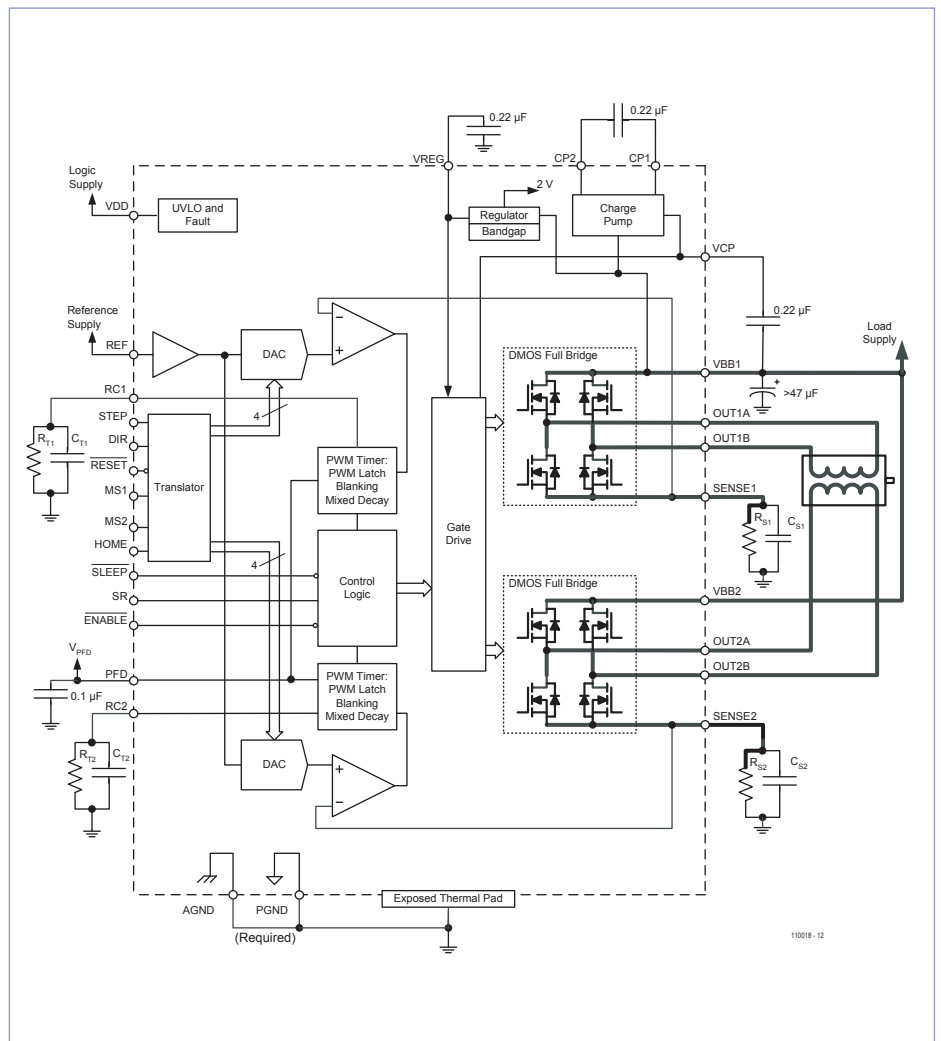


Figure 1. Block diagram of the A3979 from Allegro Microsystems.

Table 1. Microstepping configuration.

K1	K2	K1	K2	K1	K2	K1	K2
full step		half step		quarter step		sixteenth step	

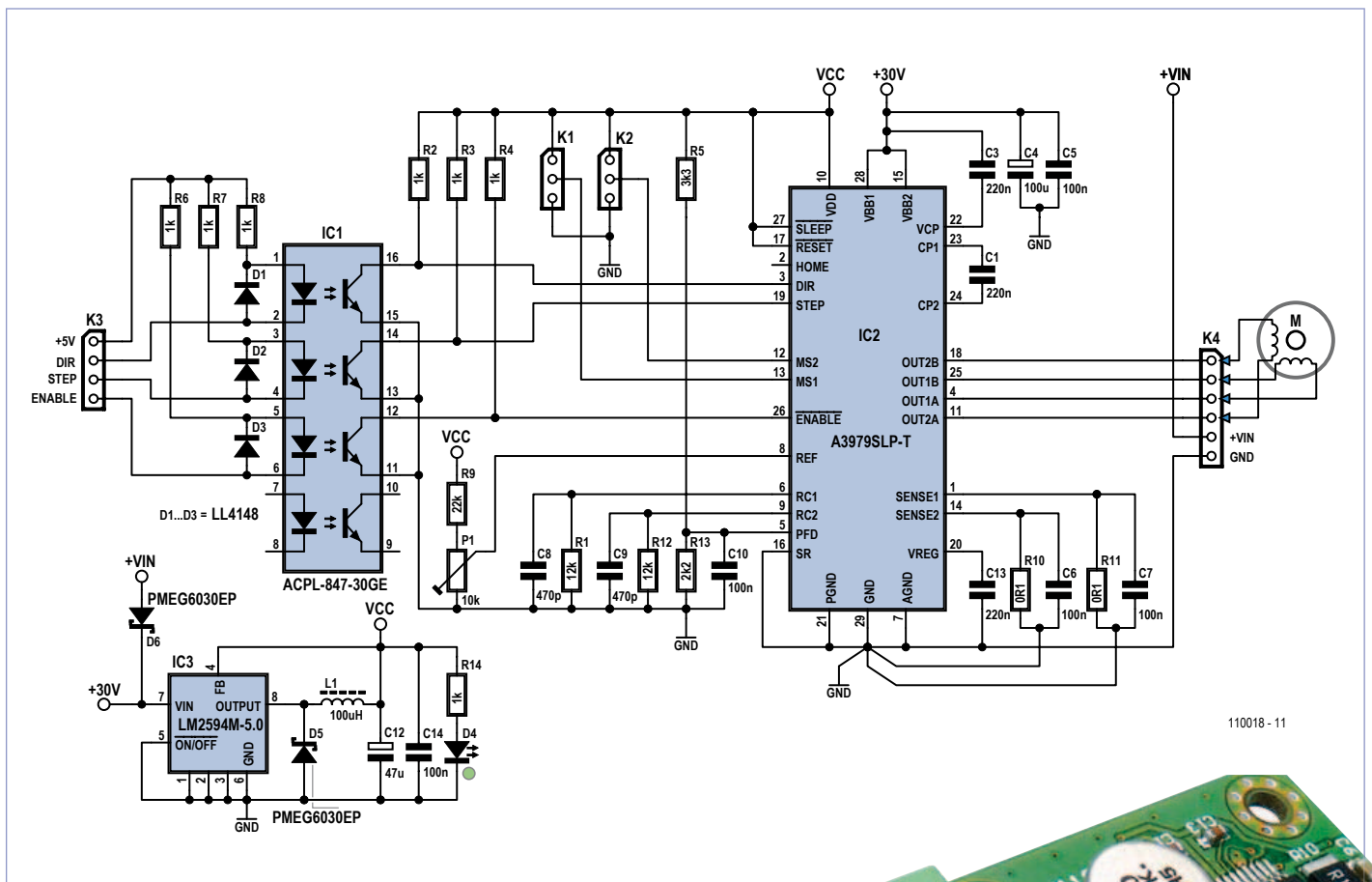


Figure 2. The complete schematic for the circuit, optocouplers provide full electrical isolation of the control signals.

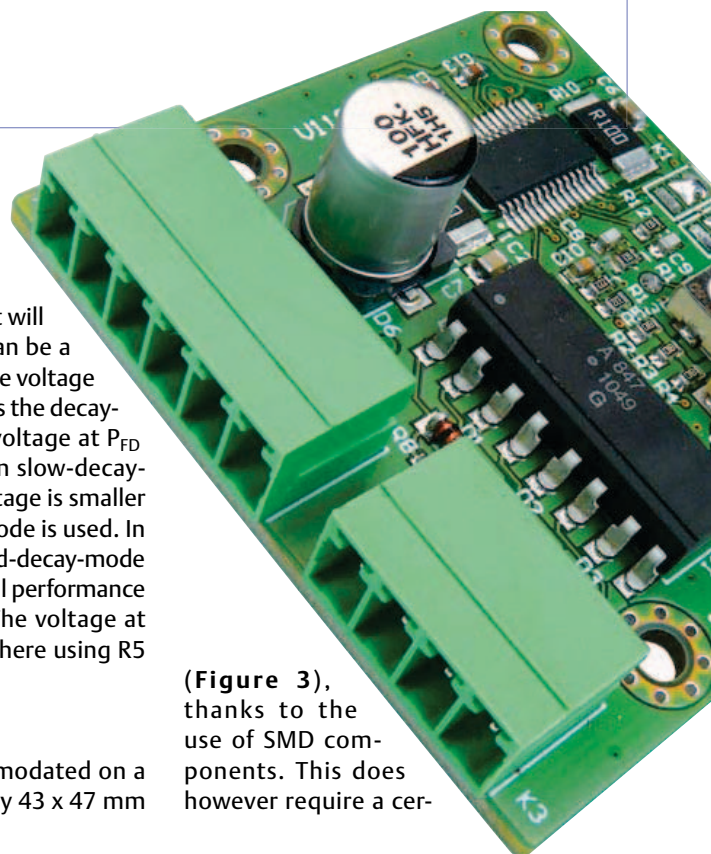
The combinations of R_{12}/C_9 and R_1/C_8 determine the duration of the off-time for the one-shot timer in the PWM generator, which sets the amount of time when the internal MOSFETs are switched off. According to the datasheet these need to have a value somewhere between 12 k Ω and 100 k Ω for R_T and between 470 pF and 1500 pF for C_T . Bipolar stepper motors have a relatively low self-inductance, which means that the blanking time for the comparator does not have to be very long. That is why capacitors of 470 pF and resistors of 12 k Ω were selected. The purpose of the blanking function is to avoid incorrect measurements across the current sense resistors at the instant that the outputs are switching. When a step results in a lower current than

the previous step, the circuit will change decay mode. This can be a slow, fast or mixed decay. The voltage across the P_{FD} pin determines the decay-mode of the circuit. If the voltage at P_{FD} is greater than $0.6 V_{DD}$, then slow-decay-mode is used. When the voltage is smaller than $0.21 V_{DD}$, fast-decay mode is used. In this circuit we chose for mixed-decay-mode because this provides optimal performance for most stepper motors. The voltage at pin 5 is set to 2 V ($0.4 V_{DD}$) here using R_5 and R_{13} .

Miniature circuit board

The entire circuit is accommodated on a circuit board measuring only 43 x 47 mm

(Figure 3), thanks to the use of SMD components. This does however require a cer-



tain amount of SMD soldering experience or a small SMD oven. The A3979 is provided with an 'exposed thermal pad' to help dissipate the heat. This has been taken into account when designing the circuit board. Underneath the IC is a solder pad with a number of vias that ensure sufficient conduction to the underside of the board, which contains a large copper plane. The thermal pad of the IC therefore has to be soldered to this solder pad at the same time as soldering the other connection pins. To be able to do this properly, the use of a hot-air solder station or SMD oven is recommended.

To be on the safe side, the top of the IC is also provided with a small heatsink with the aid of thermally conductive double-sided adhesive tape.

The only two through-hole components are the connectors K3 and K4. The types shown in the parts list are suitable for larger currents of several amps; in addition, the corresponding plugs are provided with screw connections to terminate the wires.

Current limiting

The maximum current that will flow through the windings of the stepper motor can be set with the aid of trimpot P1. This is done as follows: Using a multimeter measure the reference voltage (V_{ref}) at the test point next to the trimpot on the board.

The voltage that is set determines approximately what the maximum current will be:

V_{ref} (V)	I_{trip} (A)
0.4	0.5
0.6	0.75
0.8	1
1	1.25
1.2	1.5

Note that the maximum input voltage is not allowed to be higher than 30 V. With this the universal stepper motor driver is ready for use. Thanks to the small dimensions several of these boards can easily be mounted inside a printer or robot frame.

(110018-I)

COMPONENT LIST

Resistors (SMD 0603)

R1,R12 = 12k Ω
 R2,R3,R4,R6,R7,R8,R14 = 1k Ω
 R5 = 3.3k Ω
 R9 = 22k Ω
 R10,R11 = 0.100 Ω (SMD2512, e.g. Bourns CRA2512-FZ-R100ELF; Farnell # 1435952)
 R13 = 2.2k Ω
 P1 = 10k Ω trimpot (e.g. Vishay TS53YJ103MR10; Farnell # 1141485)

Capacitors

C1,C13 = 220nF (SMD0603)
 C3 = 220nF (SMD0805)
 C4 = 100 μ F (case F, e.g. Panasonic EE-EFK1H101P; Farnell # 9695958)
 C5,C6,C7 = 100nF (SMD0805)
 C8,C9 = 470pF (SMD0603)
 C10,C14 = 100nF (SMD0603)
 C12 = 47 μ F (SMD 6032, e.g. Vishay 593D476X9010C2TE3; Farnell # 6844626)

Inductor

L1 = 100 μ H (SMD5750, e.g. Epcos B82442H1104K; Farnell # 158896)

Semiconductors

D1,D2,D3 = LL4148 (SOD80; Farnell #9843710)
 D4 = LED, green, 20 mA (SMD 0603)
 D5,D6 = PMEG6030EP Schottky diode (SOD128; Farnell #1829207)

IC1 = ACPL-847-30GE (SOP16; Farnell #1339045)
 IC2 = A3979SLP-T (Farnell #1521716)
 IC3 = LM2594M-5.0 (SO8, Farnell #9779841)

Miscellaneous

K1,K2 = solder jumper on board
 K3 = 4-pin plug, right angled, 8A, 3.5mm pitch (e.g. Phoenix Contact 1844236 MC1.5/4-G-3.5; Farnell #1843622)
 Mating 4-way socket with screw terminals
 K4 = 6-pin plug, right angled, 8A, 3.5mm pitch (e.g. Phoenix Contact 1844252 MC1.5/6-G-3.5, Farnell #1843648)
 Mating 6-way socket with screw terminals
 Heatsink for IC2 (Fischer ICK SMD A 13 SA; Farnell #4302199)
 Matching double-side adhesive tape 6x10 mm
 PCB # 110018-1 (see www.elektor.com/110018)

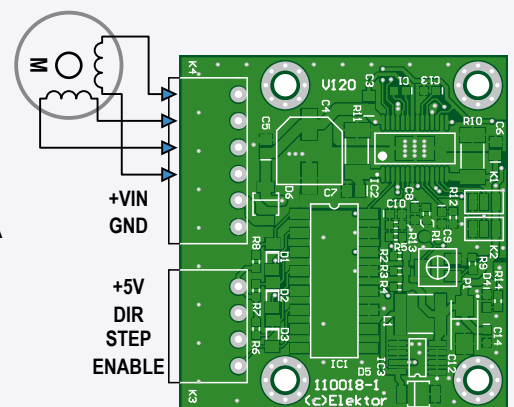


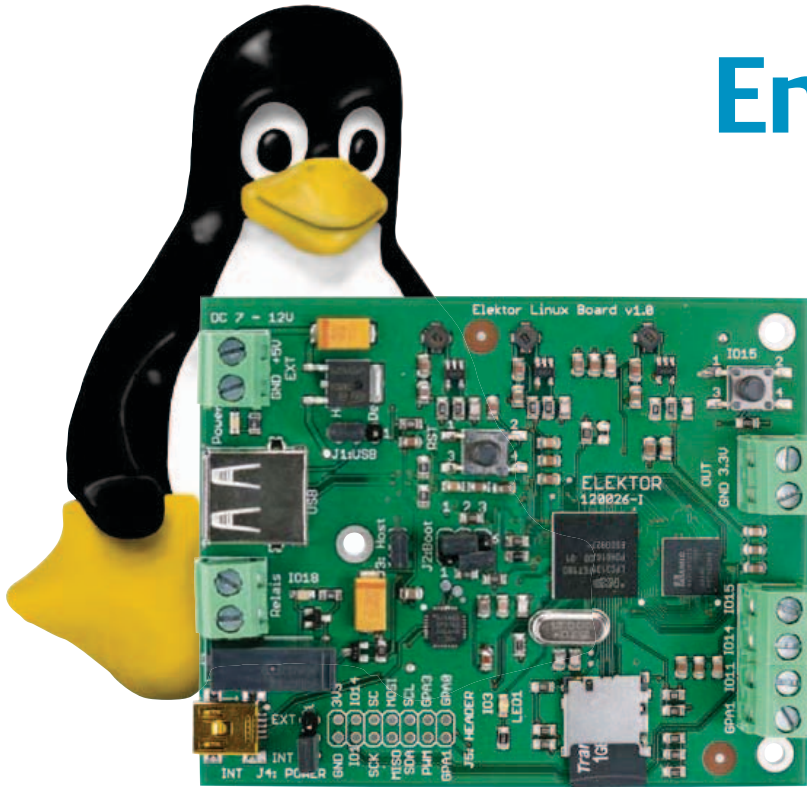
Figure 3. Thanks to the use of SMD components the dimensions of the board are only 43 x 47 mm.

Internet Links

- www.allegromicro.com/Products/Motor-Driver-And-Interface-ICs/Bipolar-Stepper-Motor-Drivers/~media/Files/Datasheets/A3979-Datasheet.ashx

Embedded Linux made Easy (2)

Hardware



Choosing a suitable microcontroller and supporting ICs is an essential step at the beginning of many a project. In this part of our course we will examine the circuit diagram of our board and look more closely at the most important components. We will then boot it for the first time and study what happens. We shall see how easy Linux can be!

By Benedikt Sauter [1]

In the first part of this series we looked at the history of the free GNU/Linux operating system and its most important elements. We now want to look at our hardware in detail: the *Elektor Linux board*.

The main components

The circuit has deliberately been kept simple: we have included only the most important components. The idea is that any reader should be able to understand the system from end to end: from applying power to launching complex applications. Running the GNU/Linux operating system requires the standard components of a computer architecture: a processor, RAM (working memory) and ROM (non-volatile memory): see **Figure 1**. How do these all work together on our board? When power is applied a mini-bootloader (roughly the equivalent of the BIOS in a PC) is started, which copies the kernel from ROM into RAM. The kernel is then started: this in turn

also has access to the ROM, from which it can copy any application into RAM as needed. We will now look at these components in more detail.

The processor

We start with the processor. It is located in the centre of the board, in a 12 mm-by-12 mm BGA package. The Linux kernel was originally developed for the x86 architecture, which is rather a different beast from that of a typical embedded processor. Because of the open way in which the programmers work and the well-thought-out structure of the software, however, it is possible to port the kernel to a range of different processors. Essential to porting Linux to a new architecture is the availability of the GNU GCC toolchain [2], which was briefly described in the first article in this series. The processor must have a hardware timer and a 32-bit architecture. An MMU (memory management unit) is not absolutely necessary, but it does help the operating system to allow different applications to run stably and independently of

one another. Each application is assigned its own virtual memory space and does not have access to the memory of other applications. The project uclinux.org [3] provided patches (see the text box) to the kernel to allow use with a processor lacking an MMU. Recently, however, these patches have been integrated into the 'mainline' kernel. In any case, we will take advantage of the MMU in our LPC3131 processor and will therefore not need to use these patches.

The LPC3131 [4] processor by NXP uses an ARM9 core (to be precise, an ARM926 running the ARMv5 instruction set). It runs at 180 MHz and has 192 Kbytes of internal SRAM; an integrated DRAM controller allows external memory to be attached. All the usual microcontroller interfaces, such as I²C, SPI and a UART, are included. There are 21 GPIO pins, four analogue inputs, an LCD interface, an I²S audio interface and a high-speed USB (480 Mbit/s) interface, which open up a wide range of application possibilities from within the Linux operating system. The *Elektor Linux board* is only double-sided, and so not all the signals can

Elektor products and services

- Elektor Linux board, ready built and tested: 120026-g1
- Free software download

All products and downloads are available via the web page for this article: www.elektor.com/120146

be brought out: however, all of the important ones are available.

The processor we have chosen is ideal for an introduction to the world of Linux as it includes only the absolutely essential facilities and peripherals, falling decidedly in the 'low cost' and 'low power' categories. Other ARM9-based microcontrollers might offer a more comprehensive range of features, but tend to be correspondingly harder to use. Nevertheless, once the basics are understood, it is relatively easy to progress to more complex devices.

Working memory

The processor itself includes just 192 Kbytes of RAM, which we will need to expand with external memory to allow us to run the kernel, the other operating system components and applications. The internal RAM is used only to run the bootloader program. Once the bootloader has configured the external memory appropriately (which includes setting up the timing parameters on the integrated memory controller and initialising the memory contents), the internal RAM is only used for speed reasons, for example as a cache for the operating system or for applications. The external memory takes the form of SDRAM (synchronous dynamic memory): these are very low-cost devices offering large storage capacities. A quick glance at the LPC3131 datasheet [4] suffices to identify find a suitable IC. We also discover that the device supports a 16-bit external data bus and a maximum address range of 128 Mbytes. A special feature is support for so-called 'low-power' SDRAM devices, which are optimised for current consumption. On our board we use an 8 Mbyte device; a 32 Mbyte device can be substituted if desired. Since the world of RAMs is standardised by JEDEC [5], a suitable device can be obtained from a wide choice of manufacturers. In the circuit we have shown the AMIC A43E26161 [6]: this is a low-power device that needs a 1.8 V supply.

The 'hard drive'

The 'hard drive' of our board is a common-or-garden microSD card (**Figure 2**), as used these days in practically every digital camera and many mobile phones. The

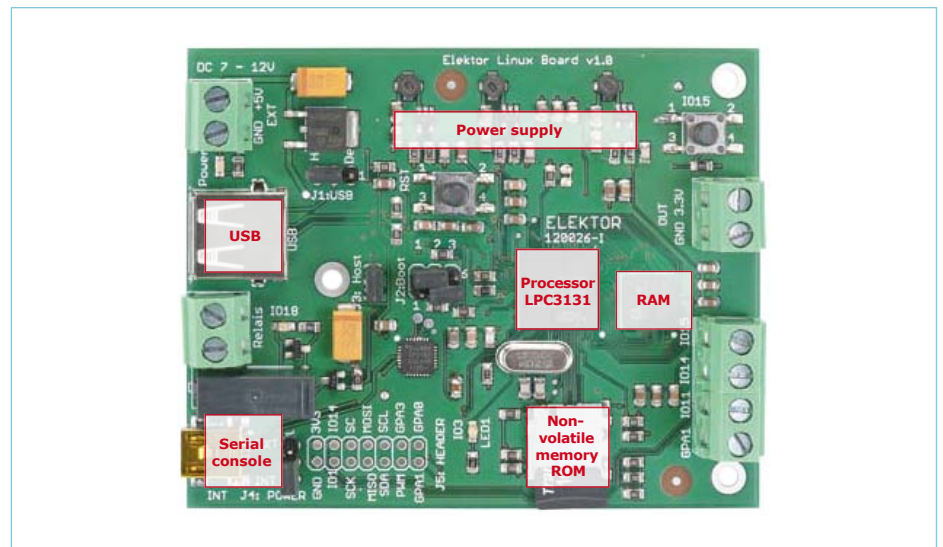


Figure 1. The main components of the *Elektor* Linux board.

card essentially consists of a NAND flash memory and a simple controller. Unlike NOR flash memory, NAND flash is always addressed by block and sector. Our standard microSD card has a capacity of 1 Gbyte, although larger cards can of course be used. As well as being readily available, microSD cards have the advantage that no special programming equipment is needed for the board: all programs and data files can simply be copied to the card using an ordinary card reader connected to a PC.

The circuit

We now turn to the circuit diagram (**Figure 3**), starting with the power supply. One possibility is to power the board using a USB cable at connector X2. The same connection can be used to talk directly to the serial console of the Linux system over USB, the CP2102 (IC7) functioning as a USB-to-serial converter.

If the system is being used without a console (for example if the UART interface is being used for a different purpose) external power can be applied at connector X6. This allows higher voltages to be applied, as an MC7805ABDT linear regulator appears between this source and the regulators for the processor proper. We suggest using a DC supply of between 7 V and 12 V. Jumper J4 is used to select whether external power or USB power is used.

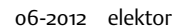
The internal 5 V rail is taken directly to the inputs of switching regulators IC1 to IC3. These have a maximum permissible input voltage of just 6 V. Resistors R4, R6 and R7 determine the output voltages of these regulators. The voltages we need are 3.3 V

for the LPC3131, 1.8 V for the SDRAM, and 1.2 V for the ARM9 core in the processor. When power is applied the 'enable' signals of the regulators (pin 1 in each case) are immediately taken high and they immediately start to produce their output voltages. Some of the more sophisticated ARM-based processors have rather onerous power sequencing requirements.



Figure 2. A microSD card and an SD card adaptor.

With the board now powered up we can turn our attention to the LPC3131 in the circuit diagram. It is device IC6, split up in the diagram into three parts labelled IC6.A to IC6.C: splitting the pins of the device into logical groups like this makes the diagram easier to understand. Block IC6.A covers all the important interfaces and I/Os of the processor; block IC6.B includes the data and address buses; and block IC6.C contains the power supply pins.



120146 - 13

In the bottom left-hand corner of the circuit diagram is U1, the SD card socket. Normally this will hold an SD card from which the Linux system firmware will be loaded. The LPC3131 is in fact capable of booting from a range of storage devices and interfaces. The options available on the Elektor Linux board can be chosen from using header SV1 (see **Figure 4**).

For example, it is possible to boot from the SD card or over the USB-to-serial bridge at X2 mentioned above. A further possibility is to boot over the second USB interface at X1 (see below), for which a DFU (device firmware update) programmer is needed.

LED1 lights when power is present on the board; also, for simple experiments or as a status indicator we have LED2. Button S1 can be used as an input device: its state can be polled on GPIO15. We have also provided a relay to control external equipment via X1. We will look in more detail at this possibility later in the series.

The overall current consumption of the board is around 85 mA to 100 mA, which corresponds to a power consumption of around half a watt.

Interfaces

Things really start to get interesting when we use Linux to access directly the various microcontroller-style interfaces provided by the processor, including digital inputs and outputs, PWM, I²C and SPI. The relevant pins are brought out to 14-way header J5 and connector X4.

GPIO

The 3.3 V-compatible inputs and outputs GPIO11, GPIO14 and GPIO15 are available on screw terminals at X4. GPIO14 and GPIO11 are simultaneously available on the 14-way header J5.

A/D channels

Three of the four channels are made available for simple analogue measurements. The 3.3 V supply is used as a reference voltage. GPA0, GPA1 and GPA3 are available on J5, with GPA1 also being available on a screw terminal.

I²C

The LPC3131 can act as an I²C bus master or bus slave. In our case the most likely option is master: this gives us an easy way to control external devices, such as a PCA9555 I/O expander). The SDA and SCL signals are available on J5.

SPI

SPI peripherals can be controlled in exactly the same way as I²C devices. The MOSI, MISO and SCK signals are available on J5, while the chip select signal OUT0 and (in the case where the LPC3131 is operating as an SPI slave) the CS_IN signal are available on test points TP3 and TP4.

PWM

A PWM output is ideal for driving a servo or for generating an analogue voltage. The LPC3131 has a hardware PWM output, and the corresponding pin is brought out to J5.

UART

The UART protocol is a particularly convenient way to implement simple communications, especially between two microcontrollers. Unfortunately the processor has only one UART, which in the normal configuration is used for the root console. If we subsequently add a network interface (see below) then it is possible to run the root console over this interface as well, freeing up the UART for other applications. The RX and TX signals are available at test points TP1 and TP2.

USB

The USB interface at K1 opens up a wide range of expansion possibilities for the Elektor Linux board. Not only do there already exist Linux drivers for a wide range of USB devices (including audio and video interfaces, 3G modems, wireless LAN, wired LAN and so on), but also many simple 8-bit microcontrollers can these days be controlled over USB. A semi-autonomous controller or coprocessor of this kind makes an ideal extension to the Linux system.

Network

It is also possible to implement a network connection, either to a wired LAN or a wireless LAN, using USB connector K1. This

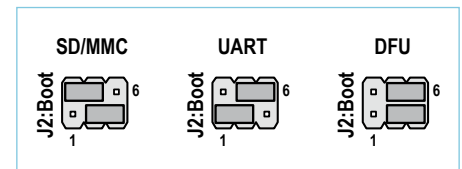


Figure 4. Bootloader jumper.

interface can be operated in ‘host’ mode or in ‘device’ mode (USB OTG, or ‘on-the-go’). In host mode any USB stick LAN or WLAN adaptor can simply be plugged into the socket. In device mode the Linux board plays the role of a USB device, for example behaving as a virtual USB network interface. We will of course describe later how this all works.

Das Boot

Before we boot the board for the first time let us take a quick look at what happens during the boot process. In order to see what is happening on the board, we need to connect it to a computer over USB and use a serial terminal program. Under Windows suitable options are Tera Term and HyperTerminal; if a Linux PC is available, you can use picocom, microcom or a similar program.

Using a standard Ubuntu system, at the Linux PC console type

```
sudo apt-get install picocom
```

and then

```
picocom -b 115200 /dev/ttyUSB0
```

to connect to the Elektor Linux board.

Under Windows things are (of course) different. The VCP driver for the USB-to-serial converter has to be installed manually [7]. Using Tera Term [8] or HyperTerminal it is then possible to select the newly-created COM port. The settings are shown in the screenshot in **Figure 5**.

Once the correct interface is selected the output from the bootloader and from the kernel should be visible in the terminal program on the PC.

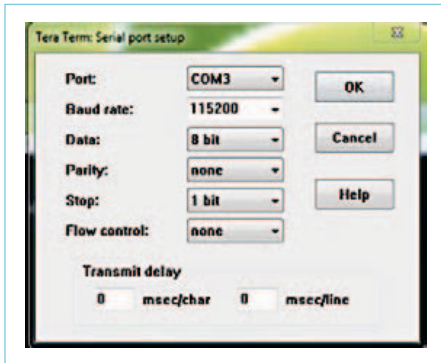


Figure 5. Tera Term terminal program.

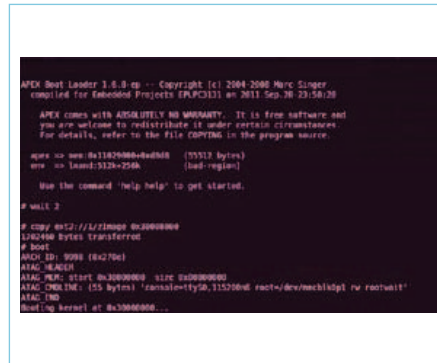


Figure 7. The APEX bootloader.

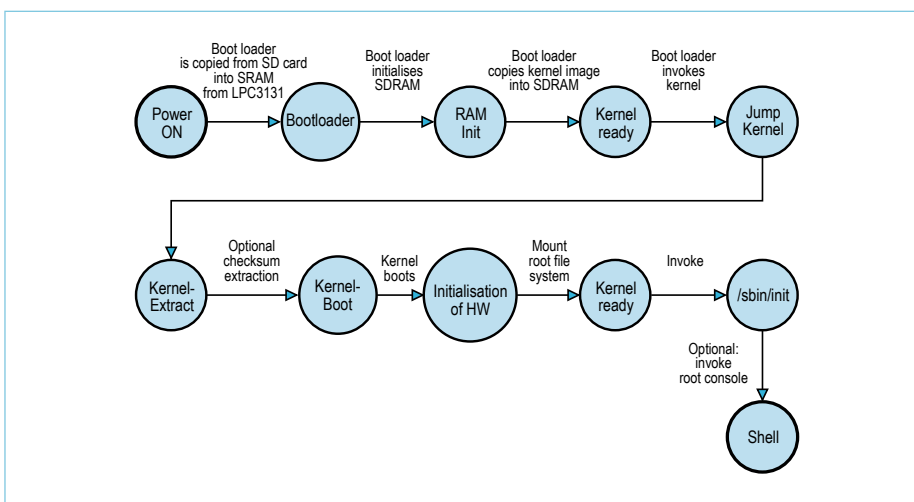


Figure 6. The boot process.

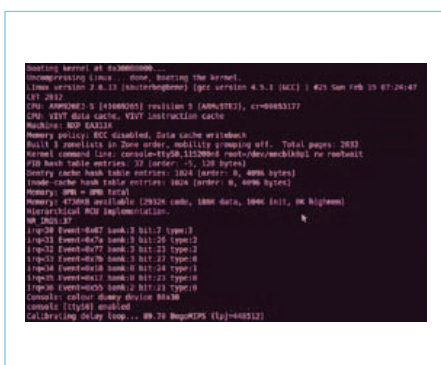


Figure 8. Messages from the Linux kernel during boot.

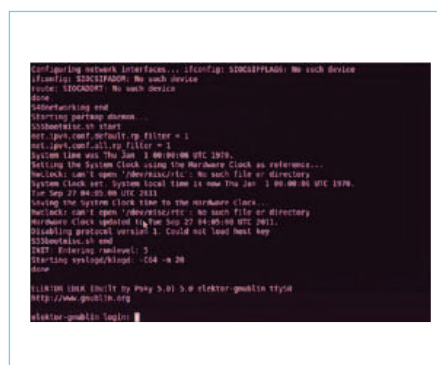


Figure 9. The login prompt.

If the boot process is already complete, simply press the reset button (RST) to repeat the process. **Figure 6** illustrates what happens during booting.

- A power-on reset interrupt is triggered.
- The internal bootloader in the LPC3131 looks for the bootloader firmware and copies it into internal RAM. Where the bootloader looks depends on the setting of the bootloader jumper: in our case we arrange for it to look on the SD card.
- The firmware that has been loaded into the internal RAM is launched.
- The firmware (the APEX bootloader) initialises the external SDRAM and copies the kernel from the SD card into the SDRAM (see **Figure 7**).
- The firmware calls the kernel.
- The kernel unpacks itself and then automatically starts up (**Figure 8**).
- The kernel initialises the hardware (including the UART for the root console).
- During the boot process the kernel mounts the root file system (which is stored on the SD card).
- The kernel launches the first process, /sbin/init.
- The kernel starts the root console on the UART interface.

The system now waits at the login prompt (**Figure 9**) for input. You can log in as the 'root' user: simply type `root` and press the Enter key.

You can now try some simple experiments using the commands that we have listed in **Table 1**. For example, you can create a test file and edit it. It is equally easy to create a new directory. With a little practice using the file system will become second nature.

As a very simple taste of what is possible, we will show how to switch the red LED on the board on and off. To do this we exploit a fundamental principle of Unix operating systems: everything is a file! Every device is represented in the file system as a file, which can be read from and written to. This even applies to our LED!

First enter the following commands.

```
cd /sys/class/gpio
```


Source code terminology

Patch

A 'patch' is a file that can be used to make changes to original source code with the help of a suitable utility program. If, for example, you make an extension to a program, you can use a utility to determine the differences between your new version and the original and generate a patch file to represent them.

Members of a development team can also use patches to help ensure that they are all working with the same version of the source code. Patch files form the backbone of open source development, where all large-scale projects are worked on simultaneously by many developers.

Mainline

The development of large-scale open source projects is organised in various ways. In general there is a single maintainer who looks after the source code, applies patches from other developers, and regularly releases new versions of the software to users. In the case of the Linux kernel there is the so-called 'mainline', which is maintained by Linus Torvalds and his team.

Since there is an enormous number of patches being offered to extend the kernel it often takes some time before a new feature will appear in the mainline. Before this point it is possible to obtain patch files directly from their developers (for example via their

home pages) and apply the patches to the kernel yourself. The aim, however, is to get everything into the mainline.

Maintainer

The maintainer is usually a single person (often the founder of the project). He or she looks after the master version of the source code, applies patches, and regularly releases new versions of the source code. In the case of Linux the various subsystems such as network, drivers, file system and so on each have their own maintainer, who is responsible for the source code and who helps ensure its stability and availability.

```
echo 3 > export
cd gpio3
echo out > direction
```

These configure the relevant port pin as an output. Then enter

```
echo 1 > value
```

to switch the LED on, and

```
echo 0 > value
```

to switch it off again. See how simple Linux can be?

Before we finish, we should explain how to power the board down safely (like a PC). As Table 1 shows, the relevant command is called `halt`. As soon as the system replies with the message 'System halted,' power can be removed.

What the future holds

In the next article in this series we will download some source code for the first time and write a small program. A somewhat longer part of the course will cover the installation of a development environment. Here too, however, we will make things as

easy as we can for readers by providing a ready-made image for download, which can be used in a virtual machine.

(120146)

Internet Links

- [1] sauter@embedded-projects.net
- [2] <http://gcc.gnu.org>

- [3] www.uclinux.org
- [4] <http://ics.nxp.com/products/lpc3000/datasheet/lpc3130.lpc3131.pdf>
- [5] <http://www.jedec.org>
- [6] www.amictechnology.com/pdf/A43E26161.pdf
- [7] www.silabs.com/products/mcu/Pages/USBtoUARTBridgeVCPDrivers.aspx
- [8] <http://tssh2.sourceforge.jp>

Table 1: Important Linux commands

Command	Description
<code>ps ax</code>	Display all processes
<code>free</code>	Show memory use
<code>date</code>	Show current time and date
<code>touch test.txt</code>	Create empty file called 'test.txt'
<code>rm test.txt</code>	Delete file 'test.txt'
<code>nano test.txt</code>	Open file 'test.txt' in an editor (use control-O to write the file, control-X to leave the editor)
<code>df</code>	Show partitions
<code>mkdir test</code>	Create a directory called 'test'
<code>cd test</code>	Descend into the directory called 'test'
<code>cd ..</code>	Move one level up in the directory structure
<code>rmdir test</code>	Delete the directory 'test'
<code>cat /proc/cpuinfo</code>	Display the contents of the file '/proc/cpuinfo'
<code>halt</code>	Bring Linux system to an orderly halt

Computer-driven Heliostat

Follow the sun or the stars



A heliostat is a device that tracks moving objects in the sky. This way you are able to extract the maximum amount of sunlight, take a series of photos of a moving planet or track a satellite for the best radio or TV reception with a dish. In this article we describe a simple heliostat that uses two servo motors. The servos are controlled via a PC program.

By Zeno Otten (The Netherlands)

This project shows an example for a heliostat, built using two servo motors. The position of the sun with respect to time and the location on Earth is calculated using a mathematical model. The result is used to drive the servos and make them point in the direction of the sun.

The prototype described here can be easily expanded to a larger and more robust system so it would be able to position an actual solar panel for it to receive the maximum possible amount of light and hence absorb as much energy as possible.

Positioning with motors

When an object needs to be positioned using a computer or microcontroller it is often the case that stepper motors or servo motors are used.

A stepper motor can be set to its required position using a relatively simple pulsed control signal. On top of that, they tend to have a high torque. The stepper motor can therefore hold its position fairly easily when it is at rest. The disadvantage is that with

a directly driven drive-shaft the minimum rotation is usually 1.8 degrees or more, due to the motor's stepping angle. Another disadvantage is that there is no feedback between the position of the drive-shaft and the number of pulses sent to the motor.

A servo motor has less torque, but has the advantage that the drive-shaft can be set steplessly to almost any position because of the use of a proportional control circuit and a potentiometer built into the motor. This circuit also makes it possible for the servo to correct any change in position caused by external forces.

A servo is also controlled using a pulsed signal, where the pulsewidth determines the angle of rotation of the servo arm.

The choice for the type of motor for our project isn't very important. Since Elektor has had several articles on stepper motor control circuits, we thought it was time for a change and decided on a servo controller. Besides, this project also serves as an introduction to the graphical programming environment of Profilab. This can be used with little effort to control things like the serial port, which we'll use here to drive the servos.

Servo control

We've used two modeller's servos in the heliostat [1], one for the control of the azimuth and one for the elevation. The azimuth is the angle in degrees in the horizontal plane; the elevation is the position in the vertical plane.

To make a servo turn you need a control signal which has a pulsewidth that varies between 1 ms and 2 ms, with a frequency of about 50 Hz. The pulsewidth determines the position of the drive shaft. A pulsewidth of 1.5 ms, for example, will cause the servo to move to a central position. A pulse of 1.25 ms will make the servo turn 90 degrees anti-clockwise, whereas a pulse of 1.75 ms will turn the drive shaft 90 degrees clockwise. All values in between will cause the drive shaft to turn by a proportional angle. However, these values could deviate by a few percent, depending on the type of servo.

The control signal for the servo should be +5 V, whereas the supply voltage to the motor may vary between 4.8 V and 6 V.

In **Figure 1** you can see the schematic for the 'circuit' to drive two servos via the serial port. Two PC817 optocouplers optically iso-

late the DTR and RTS signals of the serial port from the supply voltage and control signals for the servos. The circuit converts the signal level of the serial port ($\pm 12\text{ V}$) into the 0/5 V required by the servo. With a computer program that generates the pulses it becomes a simple matter to control the two servos.

The advantage of this simple interface is that we can also control the servos via a USB port when we add a USB/serial converter. The next step is to generate the pulses with a pulsewidth between 1 ms and 2 ms and frequency of about 50 Hz.

Graphical programming with Profilab

Programming can be fun, but for many computer enthusiasts it is often too high a barrier to overcome and successfully complete an electronics project.

In this project use is made of the graphical programming environment called Profilab [2]. Programming in Profilab could hardly be any simpler. By connecting pre-programmed functional blocks together, the programmer can create a complete program without writing a single line of code. The way it works reminded us a bit of LabVIEW. For communications with the outside world it's possible to directly drive the serial and parallel ports from within Profilab. Profilab also supports many hardware interfaces made by various manufacturers. In the programming environment offered by Profilab it is possible to compile the project into a standalone program. This program can then run on any (Windows) computer without the need of the programming or development environment.

As an example, **Figure 2** shows a simple Profilab program. The value of the slider control (SR1) varies between 10 and 20. These values have been set in the parameter section of SR1. The slider control is shown on the front panel of the program. Block ADD1 adds this to the value of block FV2, although here it is set to zero. Block GAIN1 multiplies output A by 0.0001, which results in a signal with a value between 0.001 and 0.002. This signal is presented to function block PG1, which is a pulse generator where the high-time and low-time (TH and TL) can be set independently.

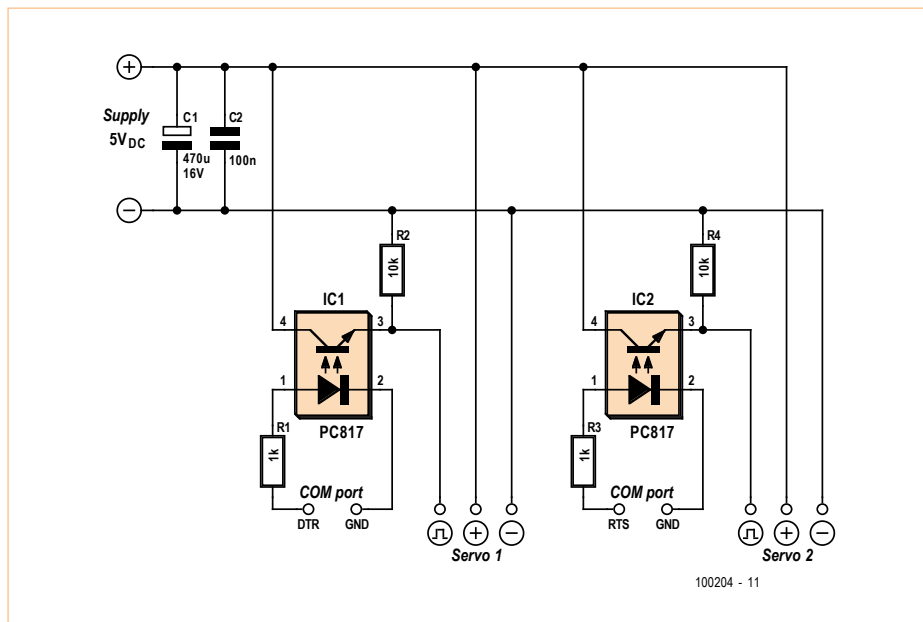


Figure 1. The electronics for driving the two servos is very simple.

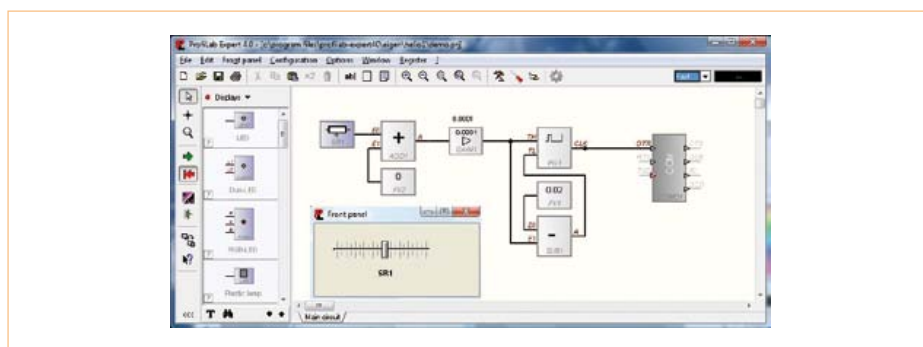


Figure 2. A straightforward example of a Profilab program.

The TH signal is also fed to block SUB1. The value of 0.02 from block FV1 is then reduced by this amount. This difference is then fed to the TL input of block PG1. The unit of simulation time in Profilab is one second. While the program runs there will therefore be a pulsed signal on the DTR pin of the serial port with a pulsewidth between 1 ms and 2 ms (depending on the setting of SR1) and a frequency of about 50 Hz. This is exactly what's required to drive a servo. The possibilities offered in the programming environment of Profilab are very extensive. However, things get much more interesting when we add a custom-written

functional block. Profilab supports this and lets you import a dynamic link library (DLL). We use this facility in Profilab to include the calculations needed to make the heliostat track the path of the sun.

The heliostat model

There are many mathematical models available that return the position of the sun with respect to any position on Earth at any time. The mathematical model used here [3] is very accurate and it can calculate the sun's position in the horizontal plane (azimuth) and the height of the sun (elevation), given in degrees. There is not much point in this

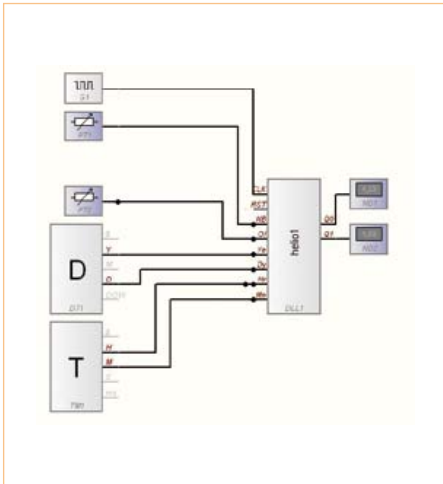


Figure 3. A specially written DLL takes care of the calculations for the position of the sun.

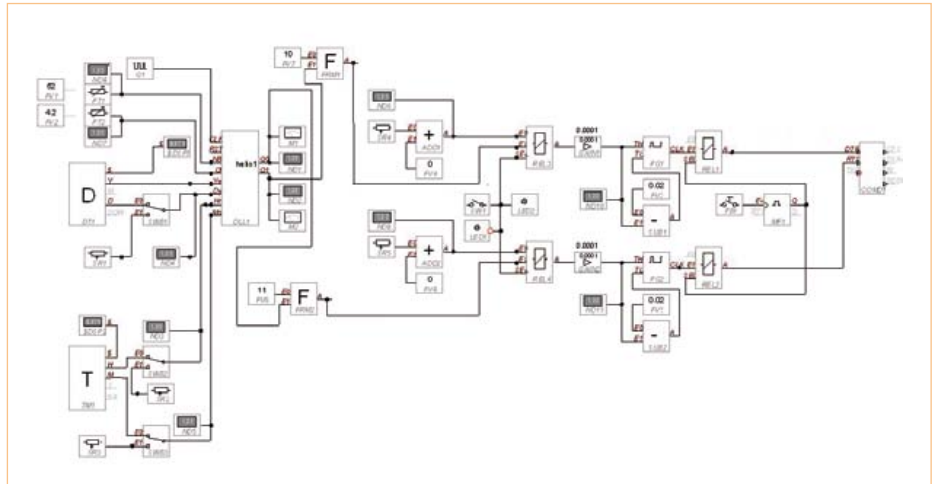


Figure 4. The complete program for calculating the position of the sun and driving the servos.

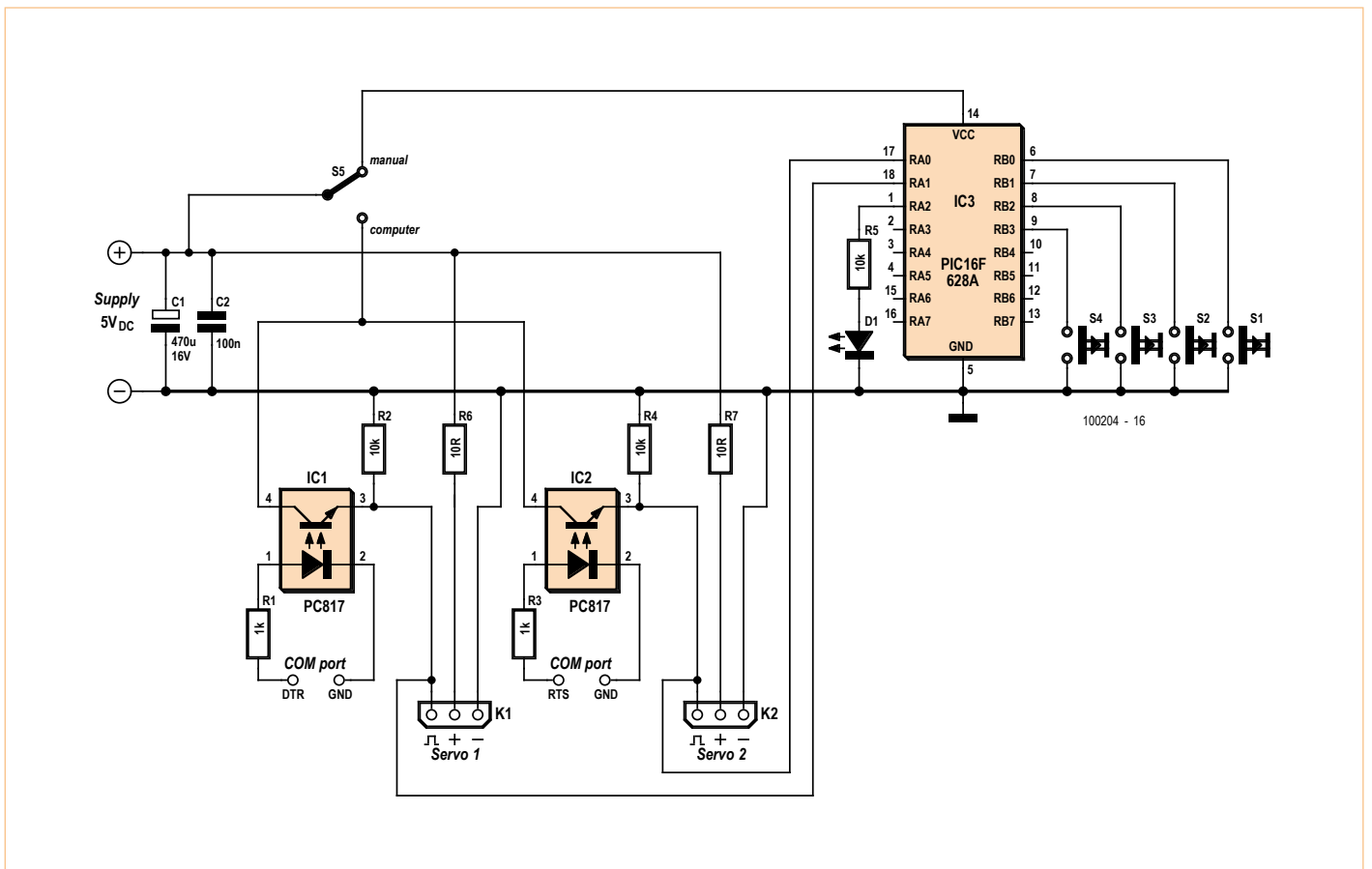


Figure 6. With the help of an extra PIC you can add manual control.

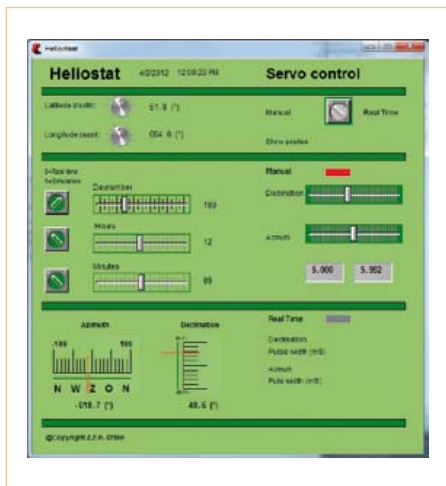


Figure 5. A view of the front panel. You can choose between real-time calculations or manual control.

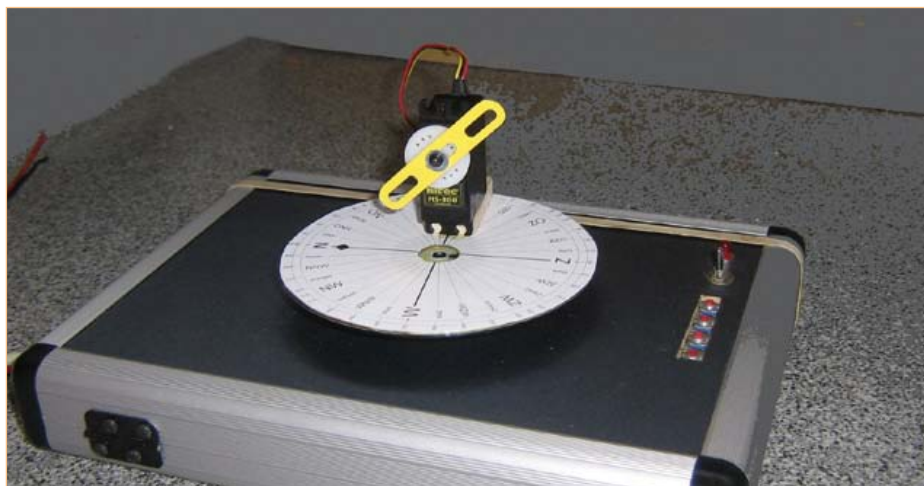


Figure 7. A practical implementation of the heliostat. One servo is mounted on a case, the second is on a CD. The 'arm' on the servo points in the direction of the sun.

application to position the heliostat with an accuracy of tenths of a degree, but since we're using a computer with ample processing power it won't do any harm either if we do the calculations very accurately. There is an example in the help-files of Profilab that explains clearly how you can include your own programming in a DLL file. All you have to do is to define all inputs and outputs of the block and then write the program code that defines the relation between the inputs and outputs. Both Pascal and C++ are supported. The model used here was written and compiled in Borland C++. In **Figure 3** the file helio1.dll is used in Profilab to calculate the position of the sun. This block has eight inputs and two outputs, Q0 (the azimuth of the sun) and Q1 (the elevation of the sun). Four inputs of helio1.dll get their information from the standard functions for the date and time in Profilab. Block DT1 sup-

plies the year (Ye) and the day (Dy). Block TM1 supplies the time of day as the hours (Hr) and minutes (Mn). The other information required is the location on Earth. This is input with the help of PT1 and PT2. PT1 supplies a value between 0 and 90 degrees north. PT2 supplies a value between -180 and +180 degrees east. G1 is a pulse generator that makes sure that a new calculation will be carried out every second by helio1.dll. The complete Profilab program is shown in **Figure 4**. Several other functions have been added so that the program can carry out simulations with regard to the position on Earth and the time. REL3 and REL4 are used to switch between manual operation of the servos (with the help of slider controls SR4 and SR5) and automatically via the mathematical model. Furthermore, an interface has been added to drive the two servos via the serial port.

After pressing push button PB1 the calculated pulses are sent to the serial port for the next two seconds. If you want to drive the servos continuously then this push button should be replaced with a continuous signal.

Every program in Profilab has an accompanying front panel. This acts as the control interface for our program. The control panel belonging to **Figure 4** is shown in **Figure 5**. Two analogue meters are used to show the azimuth and elevation of the sun. Immediately below these the position is shown numerically in degrees. When the servo control is set to 'Manual' the servos can be controlled using slider controls. When it is set to 'Real Time' the true solar position is shown. The indication is with respect to the north. When the switch 'Show position' is pressed the pulses will be sent to the servos for two seconds and the heliostat will move to the calculated direction.

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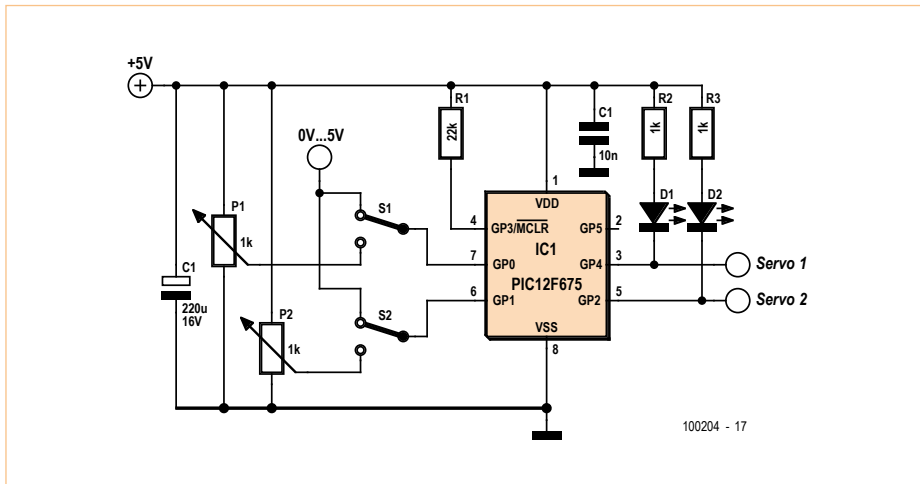


Figure 8. If you want to be less dependent on the timings under Windows you could drive the servos with analogue signals via this circuit.

Expansion 1: Manual control

Up to now we needed a computer to carry out the calculations and to drive the servos via the serial port. In order to drive the servos in situations where a computer isn't available the circuit from **Figure 1** has been extended with a small microcontroller, a PIC 16F628A (**Figure 6**). This inexpensive controller is provided with a simple program that can generate pulses for the servos. The program was written using the (free) Proton BASIC Compiler and was then programmed into the PIC using a PIC programmer from Velleman (K8048). Of course, you can also use any other suitable programmer. The BASIC program for the PIC 16F628A can be found in the software suite that can be downloaded from [5].

When S5 is switched to 'manual' the supply for the computer interface is turned off and the PIC is connected to the supply. LED1 will then flash a few times to indicate that the controller is now active. Switches S1 to S4 can now be used to generate the pulses that make the servos turn to their required position. Extra 10 Ω resistors have been put in series with the supply to the servos so that they operate from a slightly lower voltage than the PIC.

Figure 7 shows the prototype of the heliostat. On the first servo a disc (an old CD) was mounted, on which a compass rose was glued. The second servo was then glued on

top of this disc. An 'arm' was then mounted to the drive-shaft. It's this arm that points in the direction of the sun. In the photo you can also see push buttons S1 to S4 and switch S5 (computer/manual control).

Expansion 2: Analogue control

Accurately generating pulses with a pulsewidth between 1 ms and 2 ms is quite tricky to achieve in a multitasking environment such as Windows. The result of this is that the heliostat sometimes jitters a bit when the operating system is particularly busy. To get round this, we have also designed a servo controller that can be driven by an analogue voltage.

Since the PC itself cannot generate analogue voltages directly, we've resorted to a USB interface card (K8061) from Velleman [4]. This is able to output analogue voltages between 0 and 5 V and is fully supported in Profilab. We also made our life easier by using a standard 'pan & tilt' kit made by Lynxmotion. This kit is supplied inclusive of two Hitec servos [6]. To drive these two servos with analogue signals we've made use of a PIC12F674. This small controller is able to read in two analogue voltages at a resolution of 10 bits. In the circuit diagram in **Figure 8** you'll see that the analogue voltages are connected to pins 6 and 7. S1 and S2 are used to switch between the voltages set by P3 and P4, or the volt-

ages coming from the external interface. The servos are driven by pins 3 and 5. The two LEDs make the output signals visible. The program for reading the analogue inputs and driving the servos is also written in Proton IDE BASIC and is also included in the download suite from [5].

In order for the heliostat program to use the circuit in **Figure 8** several changes had to be made to the program in **Figure 4**. The position of the sun is now converted to a value that's translated to an analogue voltage between 0 and 5 V by the K8061.

And finally, there's one thing we'd like to mention about the servos used. They can turn through an angle of only 180 degrees. This is not a problem for the elevation where the servo has to turn through a maximum of 90 degrees. (In the UK the maximum elevation of the sun varies from 63 degrees in the south to 53 degrees in the north.). The positioning of the azimuth is limited to the position of the sun between due east and due west. This means that the sunrise (NE) and the sunset (NW) on the longest day of the year can't be tracked.

The mathematical model for the heliostat can also be used for several other applications, such as the automatic opening/closing of curtains or blinds, or the turning on and off of lights.

(100204)

Internet Links & Literature

- [1] www.hitecsrcd.com
- [2] www.abacom-online.de/uk/html/profilab-expert.html
- [3] R. Walraven: Calculating the position of the sun. Solar Energy Vol. 20, 1978
- [4] www.velleman.eu/products/view/?country=gb&lang=en&id=364910
- [5] www.elektor.com/100204
- [6] www.lynxmotion.com/Product.aspx?productID=287&CategoryID=61
Available from Antratek: <http://www.antratek.com/Servo-assemblies.html> or http://robosavvy.com/store/product_info.php/products_id/1182

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Summer preps full steam

By Thijs Beckers (Elektor Editorial & Labs)

Elektor Lab workers are finishing up the last loose ends of their lab duties related to Elektor's upcoming enhanced double summer edition — the *Project Generator Edition*, *PGE*. Extra attention is paid to the quality of this year's projects, after upping the standards already in the selection process. We set an ambitious goal for all of us, lab workers and editors alike, to bring you articles and circuit ideas from the utmost quality, with crystal clear details and lots of PCB layouts. All of this would of course be unfeasible



without our highly respected freelance contributors and experts, who we are grateful for their efforts in supporting this year's extra-thick magazine with fresh and exciting projects and circuits.

As you are reading this, editors at Elektor are finalising their texts and articles and probably look forward to a hopefully nice summer recess, after a very busy period. We hope you enjoy our upcoming PGE!

(120395)

Stabistor: zener in reverse

By Thijs Beckers (Elektor Editorial & Labs)

Every electronics enthusiast should know how a zener diode works and in what situations it comes in handy. But my bet is that 'stabistor' sounds a bit more exotic to most of you. So what does it do?

First, let me elaborate on how my attention was drawn to this component. Working on a circuit to drive an electric motor, former lab worker Chris Vossen decided to use a 2 V zener diode, which happened to be handy in our component drawer. Its label said 'BZV46-2V0'. When checking his circuit, Chris had to conclude that it didn't function properly. It was not long before he found the problem...

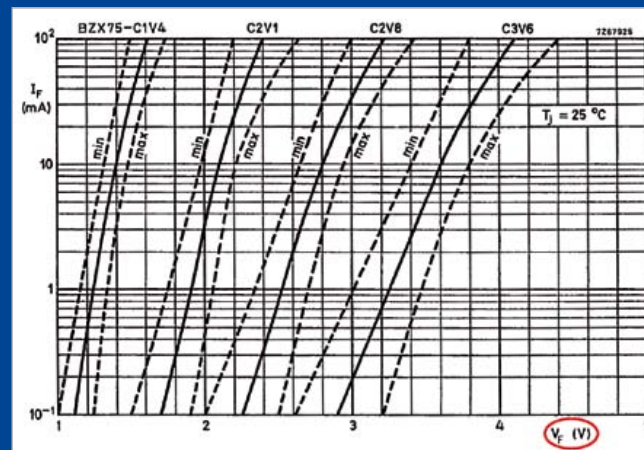
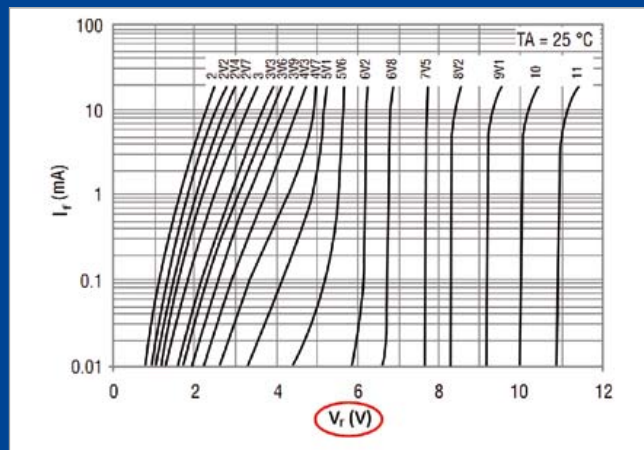
Take a close look at the curves below reproduced from the datasheet. Do you notice any differences between them (except for the scaling and the number of curves)? If you don't see it,

have a closer look at the x-axis designation in both diagrams. In the diagram of the zener diode ' V_r ' (reverse voltage) is given as the description (left diagram), while in the stabistor diagram ' V_F ' (forward voltage) is written as the x-axis designation. So... a zener diode and a stabistor are essentially the same, except for their orientation!

Since on the BZV46 the cathode is marked (just like a zener diode), it is rather tricky to get the orientation right once you find it in the 'zener' drawer and don't have a datasheet available. Once it transpired that the BZV46-2V0 is actually a stabistor and has to be soldered exactly the other way around as you would solder a zener diode, the whole circuit came to life and worked a treat.

So as a reminder to all who happen to use 'lost & found' zener diodes for low voltages from time to time: mind the polarity!

(120313)



Echoes from BOB

By Antoine “Grand Chef” Authier (Elektor Labs)

Besides our normal design work, our daily lab duties include helping out with technical questions (TQs). Some queries are a piece of cake to answer, others require a little more attention and time, and a few may be stamped “nice to know for everyone involved”. The following question from M. Da Silva should fit the last category:

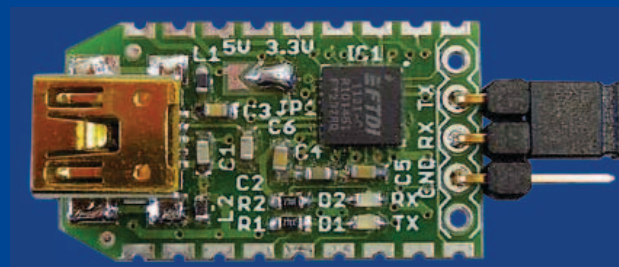
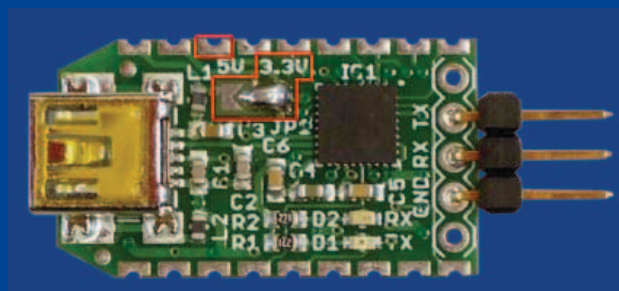
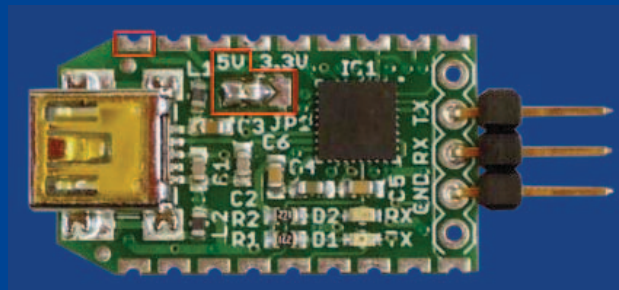
I bought four of your BOB USB converters ([1], published September 2011; Ed.) and with each one I experience the same communication problems. When I send a message from my PC to the BOB, the LED blinks and I receive a correct message at the serial output of the board. When trying to send a signal in reverse — i.e. send a message to the PC via the BOB’s input pin — neither the LED is blinking nor the message gets through to my PC. Can you please point me to the solution to my problems?

It’s highly unlikely that all four PCBs are faulty. In order to check the BOB’s functionality, the following actions are recommended:

First, check that only **one** of the two GPIO supply voltages (3.3 V or 5 V) is connected. Also, do not solder all the SMD jumper pads together. Instead, connect only one of the outer pads (associated with the required voltage) to the one in the middle by dropping a little blob of solder on them. See the first two photographs.

Then perform an echo test. No canyon required. Just connect the TX and RX pins together. This is conveniently done using an ordinary jumper, as shown in the third photograph. Now connect the BOB to your computer. In your terminal emulation software, disable the Local Echo option and send a message to the BOB. Your message should be returned instantly and appear in the terminal window. Now remove the short (jumper) between TX and RX. Sending something to the BOB should now leave the receiving window empty.

For terminal emulation you can use software like *Tera Term Pro*, which is available free from [2] and very easy to use. It also features a lot of useful functions (which allows you to make things complicated). On a contemporary computer (with no serial ports built in anymore) and with your BOB recognised correctly (always plug it in *before* starting the software), you will find the serial converter assigned as the default port in the New Connection window. The local echo is configurable via the *Setup* ->



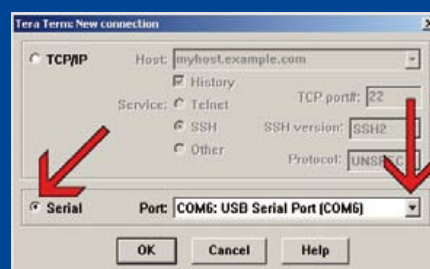
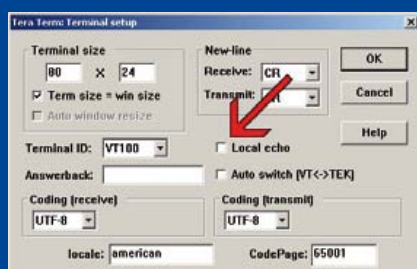
Terminal menu item by ticking or unticking a simple check box. If this little test produces positive results, it’s likely you have to look for errors elsewhere. If it doesn’t, check your settings and soldering again to make sure they are all correct before contacting Elektor Customer Services.

(120230)

Internet Links

[1] www.elektor.com/110553

[2] <http://en.sourceforge.jp/projects/ttssh2>



Dual Hot-wire Anemometer

calibrated using a Pitot tube anemometer

The slightest air leak in the shell of a building and poor adjustment of its ventilation will ruin the costly efforts made to insulate it. If your home is fitted with a dual-flow ventilation system with heat exchanger, but the sight of your heating bill sets you shivering; if you're suffering from noise pollution; if you're worried about the balance between fresh air input and extraction of humidity and pollutants — then try tracking down the north wind and other unwelcome air currents.

By Marc Gérin (France)

To measure how well a building is sealed, we go about it a bit like a inner tube: we pressurize the building so as to then measure the escaping air flow. This infiltrometry involves fitting an adjustable fan hermetically into one of the building's openings – for example, the entrance door – with all the other openings kept shut. And then we blow. The pressure difference between inside and outside the building allows an engineer equipped with a hot-wire anemometer (or a smoke generator) to hunt down the slightest leaks.

I'm offering you my toolbox for experimenting yourself in order to improve the sealing of your building and adjust its ventilation:

- a **dual hot-wire anemometer** for measuring small air leaks and balancing the dual-flow ventilation,
- a **Pitot tube** for measuring higher air speeds and calibrating the dual hot-wire anemometer. This system can also measure pressure differences up to 2 kPa.

Let's start at the end: the Pitot tube, the detector, and the display.

Pitot tube anemometer

The pressure created by a fluid moving around a solid is a function of its speed. The Pitot tube (see **inset**) exploits this principle for measuring the dynamic pressure of a fluid. Since June 2009, when the Air France Rio to Paris flight crashed over the Atlantic, everyone is now aware that Pitot tubes are used on aircraft.

Now our Pitot tube anemometer here isn't of course designed for aeronautical use, but it is nonetheless suitable for air speeds up to 200 km/h (125 mph), i.e. a pressure difference of 1,882 Pa at the tube outlet (see the Excel spreadsheet available from [3]).

Without making a habit of it, we're going to start by doing some soldering even before we take a closer look at the electronics I'm suggesting. To make our Pitot tube (**Figure 1**), drill four holes about 0.8 mm diameter peripherally around the middle of an 8 cm length of 5 mm diameter brass tube, as used in modelling. Flatten one of the ends a bit, just enough to be able to insert two 2.5 mm diameter brass tubes. To avoid

its getting blocked when you solder it, have the longer tube that passes all the way through the main tube protrude by at least 1 cm at the far end. For the soldering, using a plumber's blowlamp and flux paste, make sure you keep the pre-assembled Pitot tube **vertical**. Solder just the bottom end, to avoid the solder running down into the tube by gravity. Now turn the whole thing upside down to solder the other end. It is vital that these two ends are soldered in such a way as to completely close the gaps between the small tubes and the main tube, otherwise the static pressure measurement will be affected by the dynamic pressure.

To finish off, cut off the excess inner tube at the front end of the probe – and there you have your Pitot tube.

Pressure and accuracy

For low pressures, the data sheet for the pressure detector chosen, the MP3V5004G from Freescale, gives an accuracy of 1.5 % of the output voltage at $\frac{2}{3}$ FSD, i.e. 27 mV for around 30 km/h. This accuracy depends on the temperature, the linearity of the detector, hysteresis phenomena, and mechanical stresses. Unfortunately, the most interesting parameter, the random output deviation at low pressures, is

for tracking down draughts, adjusting a dual-flow ventilation system, or just for experimenting

not specified. So the data sheet does not enable us to deduce the behaviour at low pressures (i.e. at low speed). Fortunately, in practice we've found that if all mechanical stresses are eliminated and we allow the detector to stabilize, the random output deviation is only of the order of a millivolt or so. This is reasonable enough for measuring speeds above 15 km/h.

Standard precaution: it is vital to power the pressure detector from a separate 3.3 V rail, as any noise on its supply shows up on the output signal. This 3.3 V rail will also be the reference voltage for the separate ADC used to convert the detector output to a digital value. In this way, the analogue measuring circuit is totally separate from the rest of the circuit.

For precision of the order of a millivolt, we need at least a 12-bit ADC. I chose the ADS1100, a 16-bit ADC with I²C interface that provides eight samples per second. To improve stability, we'll be using the average of five samples per measurement, i.e. one measurement roughly every $\frac{3}{4}$ second. If necessary, to improve speed, the conversion could be limited to 14 bits. The ADC's I²C address is hard-coded on the chip. I chose the label AD0 with the address 01001000. Other addresses are possible by modifying the `adc.h` file and recompiling.

To make it easier to re-use it in other applications (modelling, level measurement, and so on), the detector is a self-contained module (**Figures 2a & 2b**). A solder bridge between pads 2 and 3 on S_{J1} connects the I²C bus pull-up resistors to the 5 V rail. To use 3.3 V, you need to make the bridge between pads 1 and 2 instead. Don't forget the via underneath the pressure detector; use fine wire, very discreetly, and flatten out the solder while it is still hot.

dsPIC for the display

For displaying the speed, I've recycled a good old general-purpose board (**Figure 3**) fitted with a dsPIC30F4011, developed for another project. It has the advantage of having a serial port, a liquid crystal display, connectivity, and can be powered via an

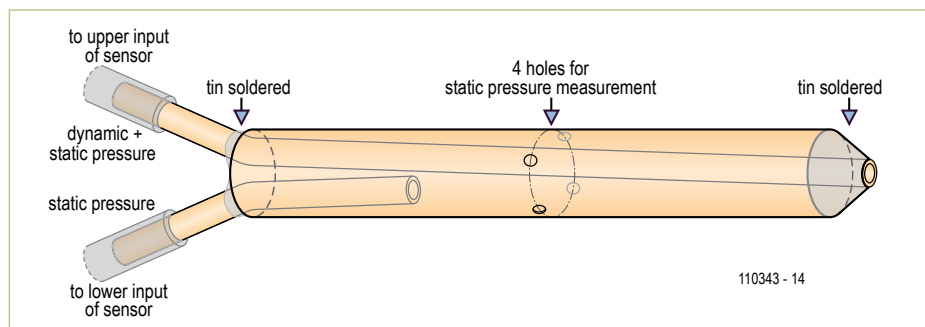


Figure 1. Used in conjunction with the pressure detector and the converter in Figure 2, this home-made Pitot tube will allow the dual hot-wire anemometer (Figure 6) to be calibrated.

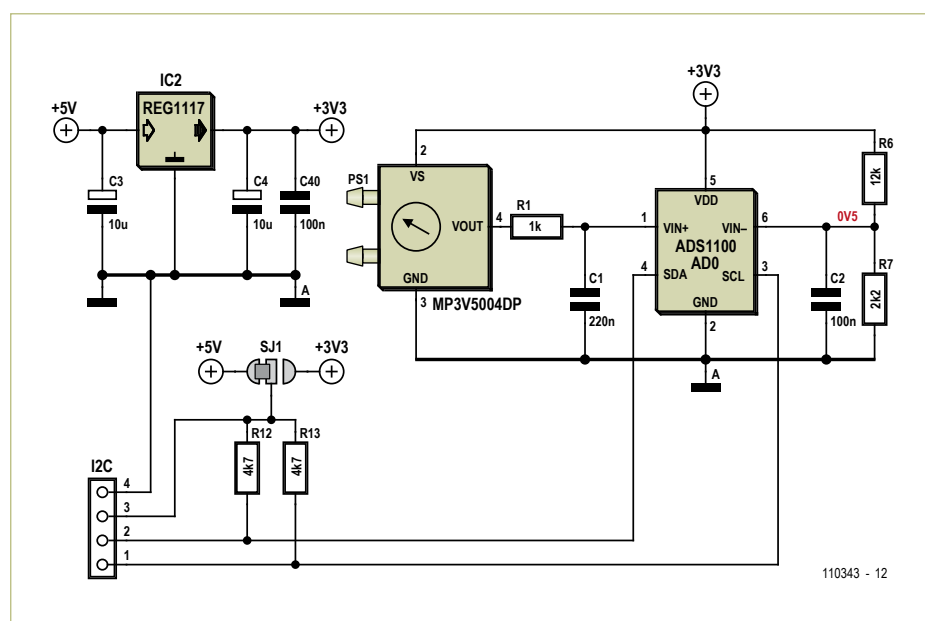


Figure 2a. Along with the Pitot tube, this pressure detector, the pressure/voltage converter, and the display (Figures 3 & 4) form an easily-calibrated anemometer.

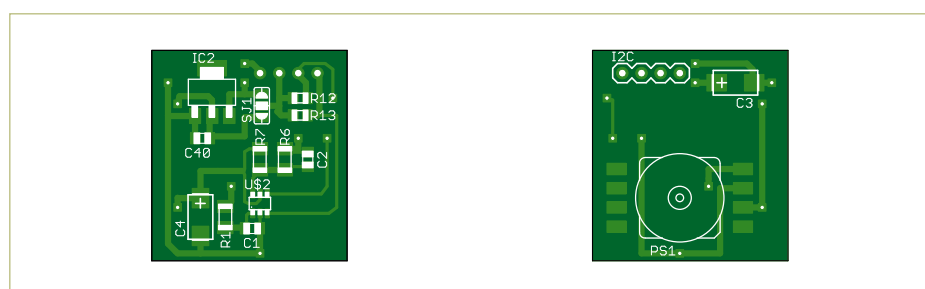


Figure 2b. I've designed this double-sided PCB for the Pitot tube anemometer.

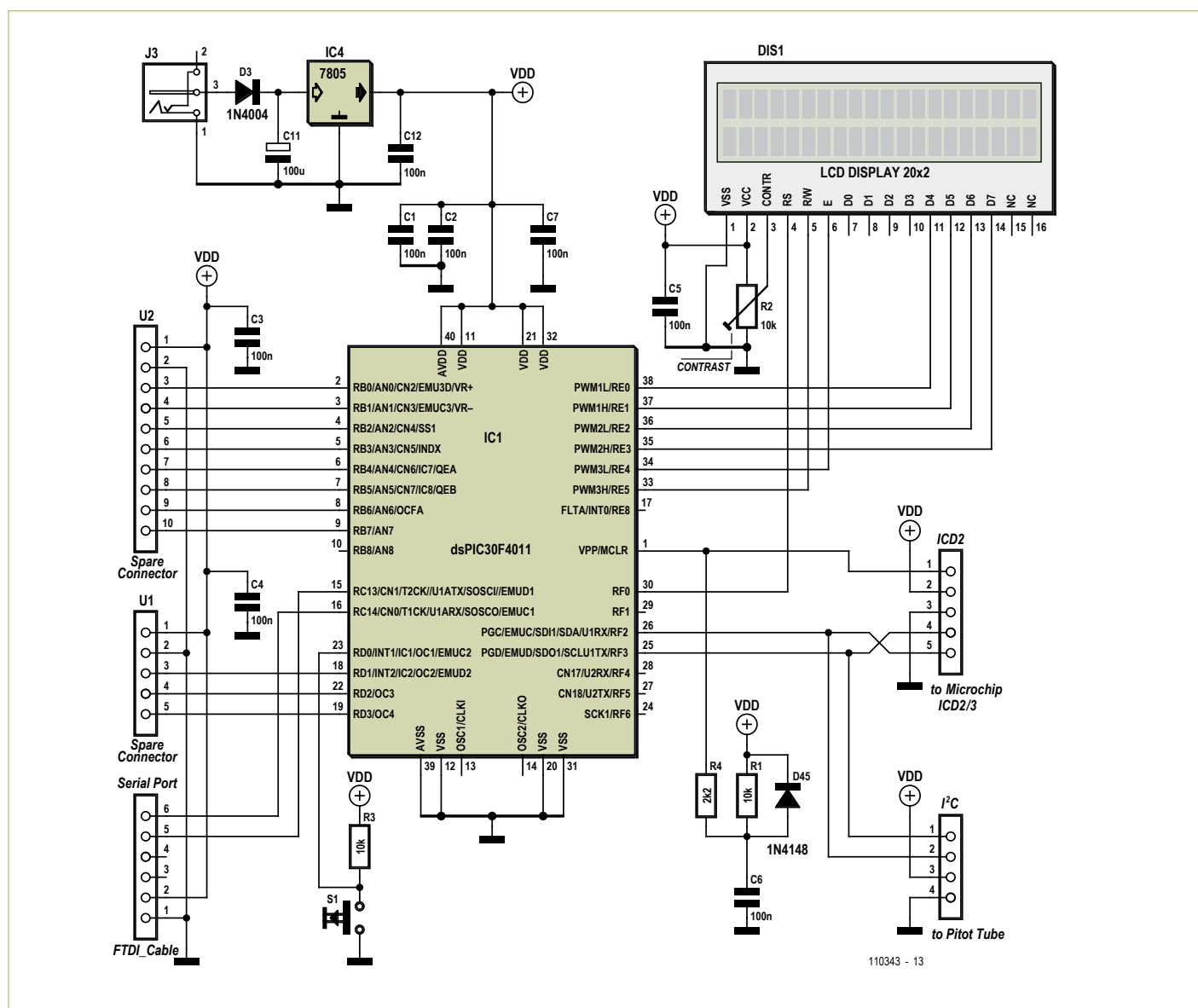


Figure 3. Circuit diagram of the dsPIC display board for the Pitot tube anemometer.

FTDI **TTL-232R-5V** USB cable [1] or by an external 9–12 V PSU. For this article, I built a second prototype (**Figure 4**).

The dsPIC program is in two parts. First of all, it handles the calibration and storage in EEPROM of the reference parameters (value from the detector at atmospheric pressure and with the pressure from a 200 mm column of water). Then, in normal operation, the program's primary loop interrogates the pressure detector, then calculates and displays the speed. It also adjusts the reference atmospheric pressure value when the button is pressed. For greater portability, the program is written using the C compiler from Microchip

and the code for each peripheral is implemented in a separate file.

Display for the Pitot tube anemometer

On the double-sided PCB, the display and push-button are on the solder side. If you don't have a through-hole plated PCB, the dsPIC and the LCD will have to be mounted using individual pin sockets that can be soldered on both sides of the board. If you're unsure about doing this, here's a little tip for soldering underneath this type of pin socket. Coat the PCB pads using a flux pen [2] and insert the contact, leaving it standing 0.25 mm above the surface of the PCB. Then apply the soldering iron tip to the

socket, and apply the solder **on the other side of the board** in the 0.25 mm gap between the socket and the copper pad: the solder will be drawn in by capillary action (a photo of this operation is available [3]). In order to insert the LCD into the sockets we've just soldered, it's best to first mount it in a male-male socket.

Implementation and configuration

The MP3V5004G detector is quite noisy, as it is very sensitive to handling. The simple fact of connecting a pipe to it and in so doing applying mechanical strain on the package will change the value measured. I recommend using silicone tubing, as used

for model aircraft hoses, carefully fixing the tubes solidly so that there are no changes in the mechanical stresses throughout the life of the project.

Leave the circuit running for around 10 minutes for the MP3V5004DP to stabilize. Then you can start the calibration (at the temperature you will later be using the Pitot tube at).

For the calibration, turn the power off and on again, keeping the button pressed until the message 'config mode' is displayed. The system leaves the detector around 20 s to stabilize, then reads the atmospheric pressure value that is going to be used as a reference. Then the message 'Put Column 200mm' will prompt you to connect up a 200 mm column of water (Figure 5).

The next step is to arrange the pipe with respect to the bottle in such a way that the air/water boundary in the pipe is exactly 200 mm below the level of the water in the bottle. Once the column of water has stabilised, the message 'Push SW when Rdy' will prompt you to press the button again to confirm the configuration and store the parameters in the EEPROM. In operation, the button can be used to recalibrate the pressure detector zero. These parameters are sent via the serial port (38400 baud) when the circuit is powered up or following calibration. In operation, the measurements are sent.

By now, you have your **Pitot tube** for measuring the air speed. Now let's move on to the dual anemometer proper.

Dual hot-wire anemometer

In a sealed building fitted with dual-flow ventilation, a proper balance between the incoming and outgoing air flows is essential, indeed obligatory. This can only improve the heat-exchanger efficiency, as well as avoiding problems of over- or under-pressure in the building.

Sadly, in most cases, people make do with a single balancing when the installation is first commissioned, and without any measurement, if you please — just by adding together the theoretical flow-rates for the various inlets and outlets. Now over time, any ventilation system goes out of balance,

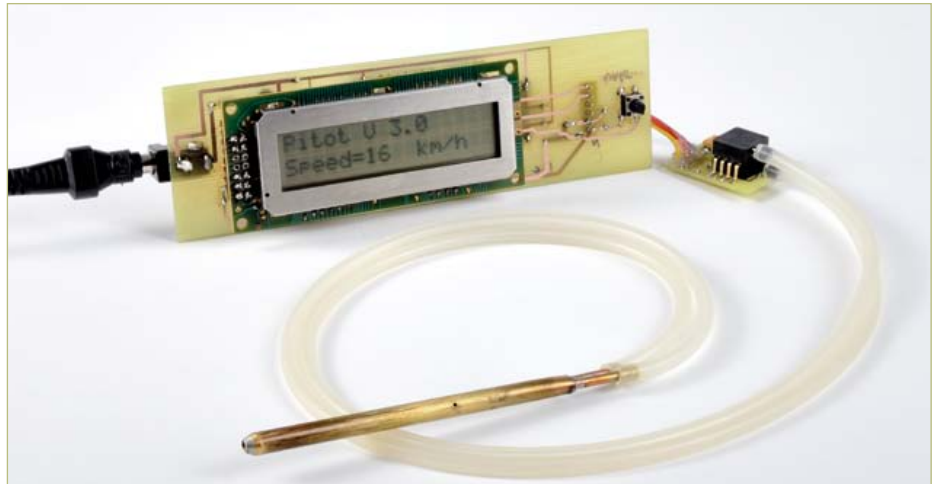


Figure 4. The second prototype for my Pitot tube anemometer.

as the supply and extract filters get blocked to a different extent. This is especially true where the external air inlet filter is a pollen filter and the extract filter is an ordinary one.

As the diameter of the ducts is the same for both supply and extract, all we have to do to find out the flow-rate is to measure the average speeds. It is then possible to balance the flow-rates simply by adjusting the motor speeds in the ventilation system's configuration menu.

The dual anemometer suggested here (Figure 6), based on the 'hot wire' principle, will let you perform this adjustment successfully or track down air leaks. The two anemom-

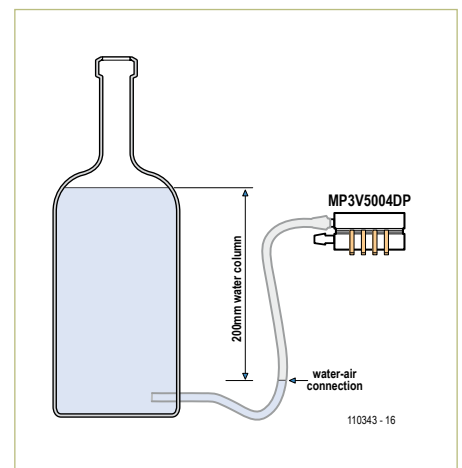


Figure 5. Calibrating the pressure detector.



Figure 6. My prototype for the dual hot-wire anemometer for dual-flow ventilation, with its two probes and the corresponding displays.

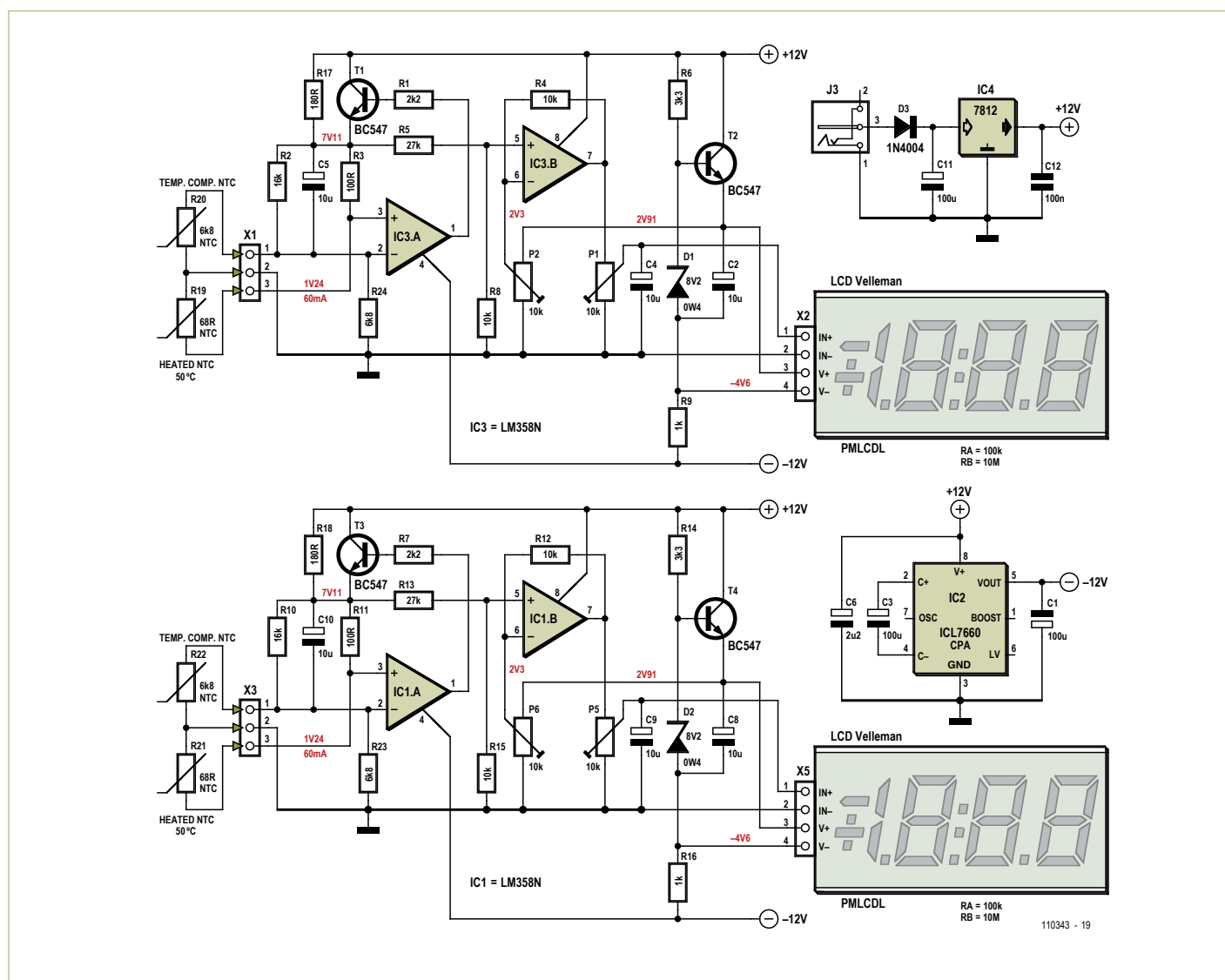


Figure 7. Circuit diagram of the dual hot-wire anemometer.

eter probes are inserted into the supply and extract ducts via small holes. My choice of a 100 % analogue circuit is justified more by nostalgia and the intellectual pleasure of it than by cost or performance factors. A microcontroller would do the job just as well – possibly better...

Thermistor probes

Our 'hot wire' is in fact a 68 Ω negative temperature coefficient (NTC) thermistor wired in a resistive Wheatstone bridge and self-heated by the current passing through it.

Temperature compensation is achieved in the second branch by another thermistor, this time with quite a high value (6,800 Ω) so it will not be heated up by the current through it. The Wheatstone bridge output

voltage will reflect the speed of the air cooling the 68 Ω thermistor.

The thermistor's operating point @ 50 °C and the thermal compensation of the whole system has been calculated using a little program [3] written using Mathcad. In addition to selecting the values for the bridge bias resistors so as to ensure the 50 °C for the 'hot wire', we also need to select values for R2, R24 and R10, R23 to ensure the best possible temperature stability. I did this by successive approximation in Mathcad.

Op amp IC3A performs air-flow measurement and temperature compensation for the first anemometer. Its inputs are connected to the Wheatstone bridge formed by R2, R3, and the 6,800 Ω and 68 Ω ther-

mistors (**Figure 7**). The values of R2 and R3 are chosen such that the bridge is balanced with just the 68 Ω thermistor at 50 °C. If the 68 Ω thermistor is cooled down by a draught, the Wheatstone bridge becomes unbalanced and the op amp reacts by varying the supply to the resistive bridge via T1. The current in the bridge increases and the 68 Ω thermistor returns to its temperature of 50 °C. Hence the bridge supply voltage reflects the speed of this draught. Clearly the same goes for the second anemometer, which uses IC1A. Resistors R17 and R18 are used to maintain sufficient current in the 68 Ω thermistor, while reducing the heating in T1 and T3.

The 68 Ω and 6,800 Ω thermistors can be seen in the photo of the anemometer probe

at the top of this article. They are connected up using fine insulated wire, long enough to minimize any thermal coupling. For the probes, I chose to use professional microphone cable that matches the diameter of the brass tube. The thermistors are fitted into little pieces of 8 mm diameter brass tube, with two holes for the air to circulate. They are each held firmly in place by a little disc of balsa, as thin as possible to reduce thermal conduction. You can use a piece of plastic tubing as a guide to help you insert the thermistors with their discs (**Figure 8**).

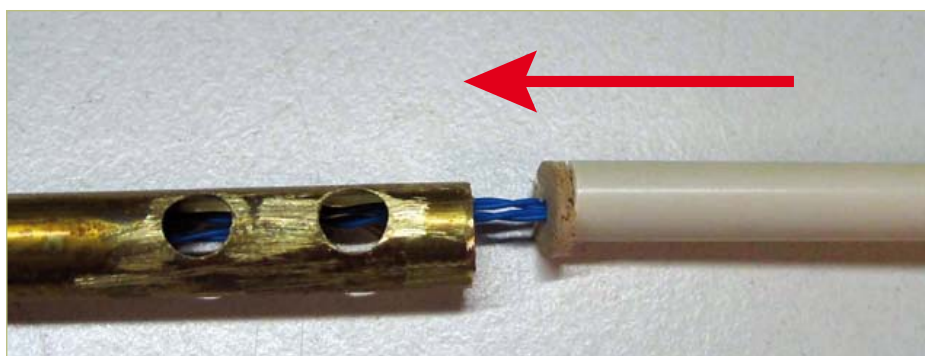


Figure 8. Use a piece of plastic tubing to insert the thermistors, the wires, and the balsa disc into the tube.

sate for the voltage offset introduced by the preceding stage (IC1A and IC3A) and to feed the potentiometers (P1 and P5) that define the overall gain of the circuit.

one in your bathroom! Zero adjustment is by way of potentiometers P2 and P6, depending on the input. Put the thermistor anemometer probes in a closed box to pro-

Tracking down those draughts!

I fixed the whole lot together by injecting hot-melt glue via a hole near the small piece of breadboard.

Here, the primary cause of errors is undoubtedly the thermal conduction of the wires connected to the thermistors. Fine adjustment was done by successive approximation on the prototype by modifying R2 and R10. The honour of the electronics engineer, soldering iron in hand, is intact.

Two displays

To display the air speed, I decided to use Velleman LCD voltmeter/display modules, which are ready-to-use, elegant, and cheap. However, the downside is that they are tricky to incorporate into a circuit where we need to measure a voltage with respect to the 0 V rail. Their differential input IN- has to be maintained at least 1 V above the display's V- rail. T2 and T4 are wired as a current source to provide a floating supply for the voltmeter, allowing their IN- to be connected to the 0 V rail (GND). As these voltmeters are fitted with a configurable input voltage divider, R_A will be 100 k Ω and R_B , 10 M Ω . A potentiometer is used for fine adjustment of this divider.

The DC/DC converter IC2 provides the negative voltage required to produce the supply for the voltmeters, as well as the negative voltage for the op amps.

IC1B and IC3B make it possible to compen-

Calibration and conclusion

We now have our double anemometer and our Pitot tube; all we need to calibrate all this is a hair-dryer. We're not going to build this ourselves – you should be able to find

test them from any possibility of draughts. Next, to calibrate the speed, place the Pitot tubes and the anemometer probe at the same height, so they all receive the same air-flow (**Figure 10**). Turn the hair-dryer on

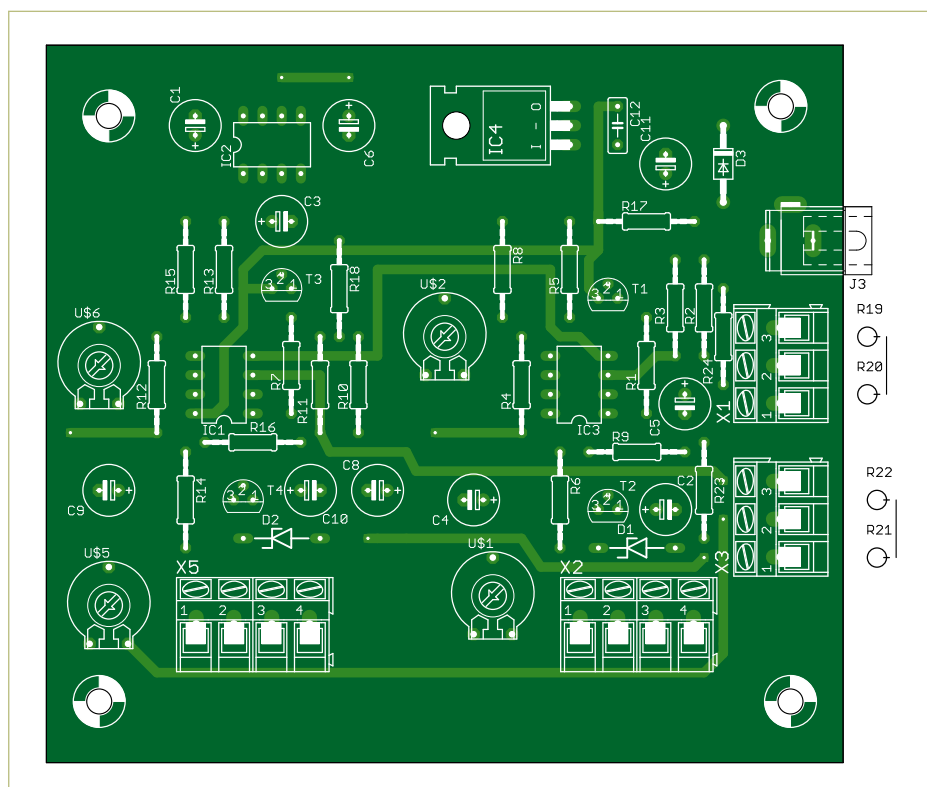


Figure 9. The PCB.

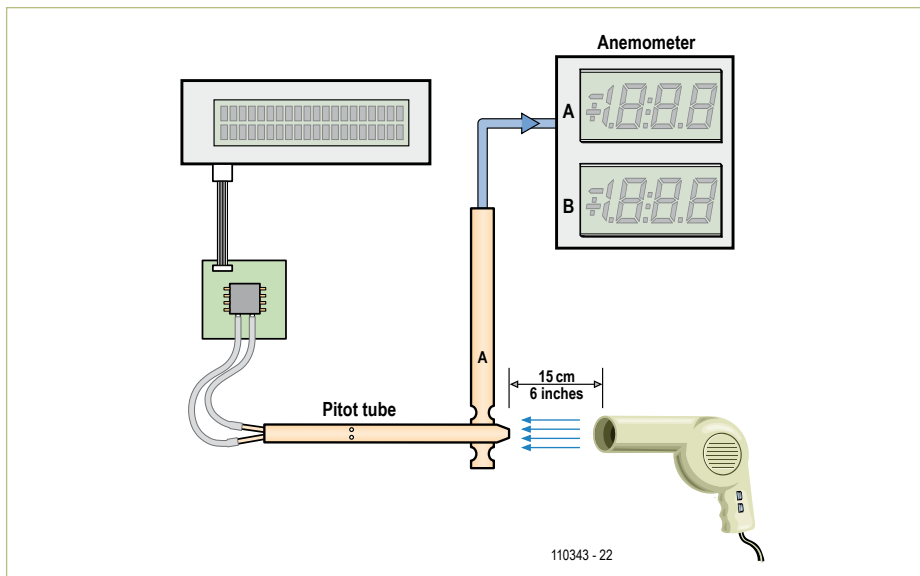


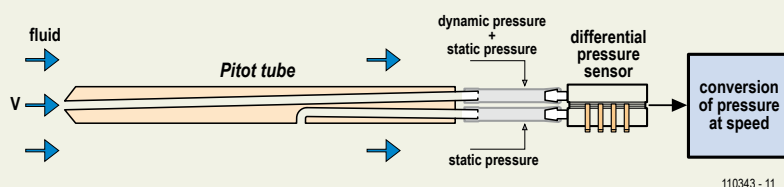
Figure 10. For the calibration, make sure you place the Pitot tube inlet at exactly the same height as the thermistors, so that the air-flow is the same for both anemometers.

('cold' position). Set P1 and P5 so that the twin displays indicate the same speed as the Pitot tube. Tweak the voltmeter gain potentiometers if necessary.

So here you are now, armed with the means to track down that chilly north wind and

easily balance up your ventilation system. Ventilating a building represents around 25 % of the energy expenditure. With a little experience, preferably on a very windy day, you'll find that the north wind's best friends are the joins between walls and window-frames, mainly in the higher parts

Pitot tube



Principle for measuring speed using a Pitot tube and a pressure detector.

The Pitot tube is used for measuring the flow speed of a fluid by performing two pressure measurements. One opening at the end of the tube makes it possible to measure the total pressure, i.e. the sum of the atmospheric pressure plus the pressure resulting from the flow of the fluid (static and dynamic pressures). Another opening on the periphery of the tube makes it possible to measure just the atmospheric pressure (static pressure). From these two measurements, it is possible to calculate the flow speed of the fluid using this equation:

$$V = \sqrt{\frac{2(p_t - p_s)}{\rho}}$$

V: speed;
Ps: static pressure

Pt: total pressure
ρ: density of the fluid

The equation is in exponential form: it will be difficult to measure low speeds because the pressure variations are very small.

About the author

Already as a baby, awoken in the middle of the night by the rumbling of my father's windmills, I had realized that the north wind and I would never be friends. As an adolescent, my teachers criticized me for preferring a soldering iron to a biro. Only my science teacher thought I set a good example. I studied as an electronics engineer, then in management, and latterly as an energy consultant.

Married, 48, the father of two magnificent adolescents, and working for Belgacom, I am now getting my own back and recruiting allies among Elektor readers so as to conquer this north wind!



of the building and around the roof. But this Mr North Wind also likes your sockets, switches, skirting-boards, and so on. And he hates you with your dual anemometer and your silicone mastic gun!

(110343)

Links

- [1] www.ftdichip.com/Products/Cables/USBTTLSerial.htm
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- [3] www.elektor.fr/110343

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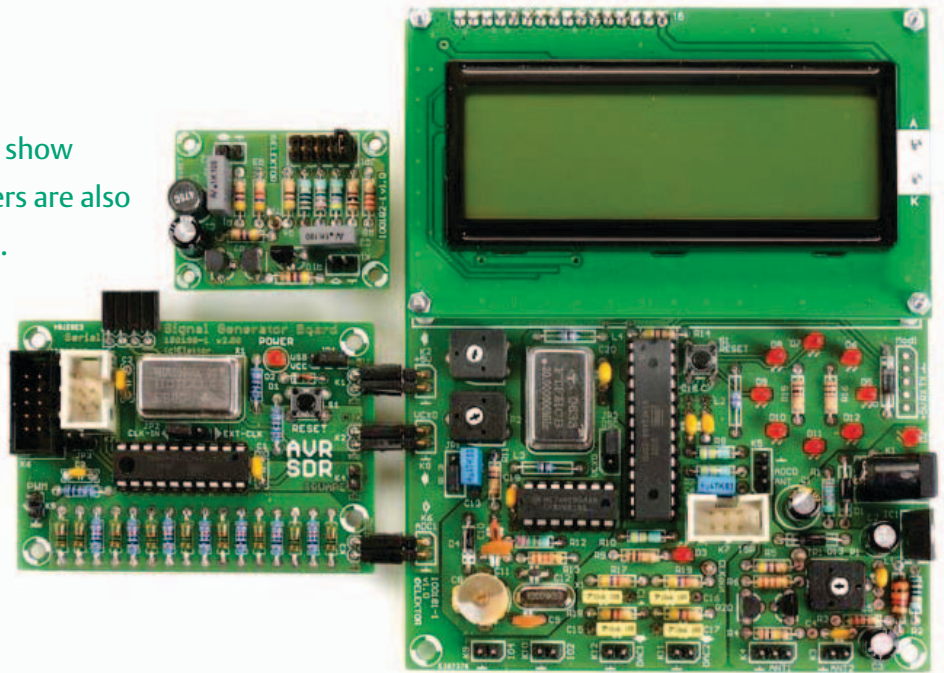
AVR Software Defined Radio

Part 4: Digital radio reception: DCF77, weather service and more

By Martin Ossmann (Germany)

The aim of this series of articles is to show that the popular AVR microcontrollers are also suitable for digital signal processing.

This time we turn our attention to something practical: using our DIY SDR to receive signals from DCF77 and other time reference transmitters, as well as the German weather service. We also decode the time and weather signals.



In the previous instalment [3] we described a test transmitter and an active ferrite antenna, which we can put to good use in this instalment. Now we dedicate our efforts to expanding the scope of our digital receiver. We have already described the digital I/Q mixer. Now it's time for the filters downstream of the mixer. In order to implement narrow-band reception, we need low-pass filters after the mixer, and more specifically the same filters for the in-phase and quadrature components. The filters located directly after the mixer operate at the same sampling rate as the front end — e.g. 10 kHz

for DCF77. The filters need to be simple to allow the AVR to compute them in real time. In the front end we use what are called CIC filters for this purpose. Now it's time for a description of how these simple filters work.

Moving-average and CIC filters

CIC filters are based on the moving-average principle. **Figure 1** shows a filter that calculates the moving average of a set of five samples.

A series of delay stages stores the past samples, which are summed for each average value. When this filter is implemented as an

algorithm, the samples are stored in a ring buffer. Each time a new sample is added, it replaces the oldest sample and the buffer pointer is incremented. All samples in the ring buffer are added together each time to calculate the output value (four addition operations). This takes $N - 1$ addition operations for a filter with N samples. A large N requires a lot of computation time.

It can be shown that the filter depicted in **Figure 2** does the same thing as the one in **Figure 1**. Linear time-invariant filters are fully characterised by their impulse response. The impulse response is the out-

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- BOB FT232 USB to TTL converter, fully assembled and tested: #

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- Free software download (hex files and source code)

All products and downloads are available on the web page for this article: www.elektor.com/120088

put signal resulting from a single '1' at the input (in the series 0, 0, 1, 0, 0, 0, 0, 0, 0, ...). The series 0, 0, 1, 1, 1, 1, 1, 0, 0, 0, ... is the impulse response of a moving-average filter, due to the fact that the single '1' passes through the five summing nodes. Now let's look at what happens to a '1' that enters the filter shown in Figure 2. This filter consists of two parts: a delay line with five stages, followed by an integrator (accumulator).

The integrator simply sums all incoming values and outputs the sum. When a single '1' enters the filter, it passes through the delay line. However, it also reaches the integrator via the direct path. The '1' remains stored in the integrator, which outputs a '1' until the '1' from the delay line also reaches the integrator. The latter is multiplied by -1, and after five steps the resulting '-1' neutralises the '1' that arrived previously, with the result that the output from the integrator consists of a string of zeros. This means that the impulse response of this filter is exactly the same string of five ones.

The first section of the filter (the delay line followed by the subtractor) is called a comb filter because its frequency response looks like a comb. This means that our filter consists of a comb filter followed by an integrator. This type of filter needs only two addition operations per time increment, regardless of the number of delay stages (N). This implementation considerably simplifies matters for microcontrollers. Here again, the delay line is implemented as a ring buffer.

As the sequence of several linear time-invariant filters may be swapped, the filter in **Figure 3** also has the same effect, but in this case the integrator is located before the comb filter.

Now let's work out whether this filter does in fact have the right impulse response. After a single '1' enters the filter, the integrator constantly outputs a '1'. The question now is how this filter responds when it receives only a series of '1' values. At some point the integrator must overflow, but if you use the right floating-point arithmetic in the implementation, the filter works properly despite this. This behaviour is essential for the usability of this filter version.

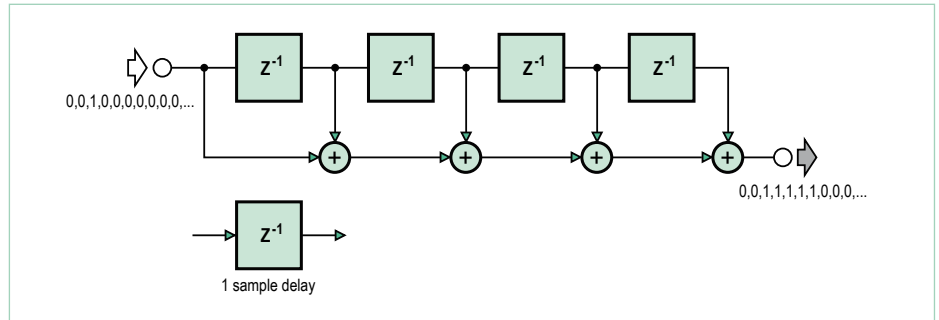


Figure 1. A moving-average filter.

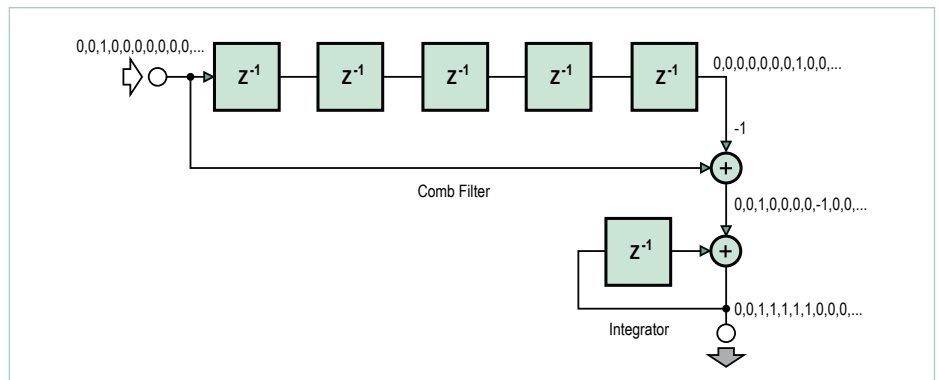


Figure 2. A five-stage delay line and integrator, which is equivalent to the circuit in Figure 1.

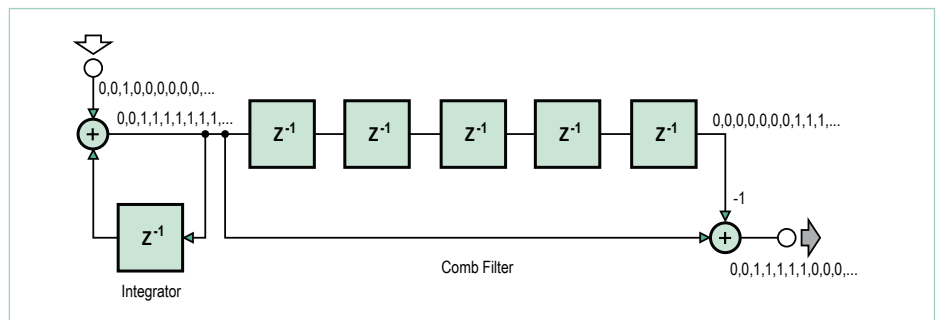


Figure 3. Filter sections in reverse order compared with Figure 2, but with the same effect.

Filters and downsampling

Due to the high sampling rate, the front end does not have much time for complicated filter algorithms. If the signal to be processed is sufficiently narrow-band, the signal can be downsampled (decimated)

by a factor R after pre-filtering. This means that only every R th sample is kept and processed. If you want to use a moving-average filter, you can use the especially efficient CIC structure shown in **Figure 4**. Here integration is still performed at the

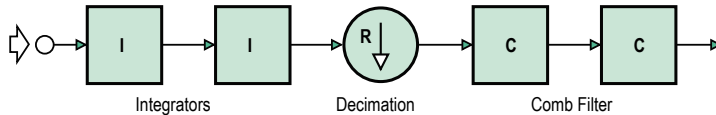


Figure 4. The CIC architecture is especially efficient.

Listing 1: In-phase channel

```
if (sampleTime & 1) {
    if (sampleTime & 0b10) {
        IIintegrator1 += ADCv ;
    }
    else {
        IIintegrator1 -= ADCv ;
    }
    IIintegrator2 += IIintegrator1 ;
}

sampleTime++ ;
if (sampleTime==Md) {
    sampleTime=0 ;
    IntFifoII[IntFifoInPtr]=IIintegrator2 ;
    IntFifoInPtr=(IntFifoInPtr+1) & IntFifoMask ;
}
```

Listing 2: FIFO filter

```
IIsample=IntFifoII[IntFifoOutPtr] ;
IntFifoOutPtr=(IntFifoOutPtr+1) & IntFifoMask ;
// do 1.st comb-step of two stage downsampling CIC filter
IIcomb1out=IIcomb1store-IIsample ; IIcomb1store=IIsample ;
// do 2.nd comb-step of two stage downsampling CIC filter
IIcomb2out=IIcomb2store-IIcomb1out ; IIcomb2store=IIcomb1out ;
```

Listing 3: Third filter stage

```
// integration step of smoothing CIC filter I-channel
IIintegrator3 += IIcomb2out / P ;
// comb step of smoothing CIC filter
IIcic3out = IIintegrator3 - IIfifo[CICfifoPTR] ;
// FIFO update of smoothing CIC filter
IIfifo[CICfifoPTR] = IIintegrator3 ;
// advance pointer and bump around
CICfifoPTR++ ; if ( CICfifoPTR==Mc ) { CICfifoPTR=0 ; }
```

fast data rate. The comb filter, which has a length of R , $2R$ or NR here, does not need to operate at the fast data rate, but only at the data rate reduced by the factor R after decimation. This significantly reduces the load on the fast interrupt routine that has to process the ADC values. Here the routine for the in-phase channel takes the form shown in **Listing 1**, where Md is the downsampling factor. The front end stuffs the samples into a FIFO buffer, from which they are fetched by the following stage. If the following stage is momentarily too slow to process the samples immediately, one or several samples remain in the buffer until they are fetched. This technique makes it easier to program the subsequent stages. **Listing 2** shows the finished code for this.

The result after double filtering is held in the variable `IIcomb2out`. As you can see, the CIC filter needs only a few addition operations. As the bandwidth after the two cascaded filters is still not sufficiently narrow, a third filter is added. This filter does not decimate the signal, but instead leaves the sampling rate unchanged. The associated code shown in **Listing 3**. Here again, only a few operations are necessary, and the number of operations does not depend on the length of the filter.

This concludes our discussion of the filtering of the I and Q signals. **Figure 5** shows the resulting architecture of the front end with the filters. Timer 1 generates the ADC sampling rate clock F_s , which has a frequency of $(20 \text{ MHz})/N_s$. Downsampling of the input signal with frequency f_{IF} yields a signal with frequency f_{IF} . This frequency must be exactly one-quarter of the sampling frequency, so that it can be mixed with the signal from the local oscillator to obtain the baseband signals. Each of the resulting signals is filtered by a triple low-pass filter. The first two filters, which are also used for decimation, are of order Md . The final filter is of order Mc . The limit frequencies of the filters decrease with increasing values of Mc and Md . The X and Y signals are available at the outputs of the filters for further processing.

Receiving frequencies

In order to apply the concept described above, the quotient of f/F_s must differ from

an integer value by exactly 0.25. As you can see from **Table 1**, this requirement can be fulfilled for a large number of receiving frequencies.

If necessary, this requirement is only needs to be approximately fulfilled. In such case the signal is not mixed down to absolute baseband, but instead to a very low frequency.

CORDIC concept for phase and amplitude

The aim of our first experiment is to receive the DCF77 signal in the same way as described in the previous instalment [3]. For this we use the software EXP-Simple-DCF77-RX-IQ-V01 [4]. DCF77 is a time standard transmitter in Mainflingen, Germany, and operating at 77.5 kHz. It controls millions of clocks in Europe.

The input signal, decomposed into the I and Q components, is available after low-pass filtering. However, in many cases what you need is the amplitude, phase or frequency. This corresponds to a conversion from rectangular coordinates to polar coordinates. With floating-point numbers the phase can be determined using the atan2 function, but floating-point computations take a lot of processing power. For this reason, we propose a method that manages with pure integer computations.

Let's start by looking at about **Figure 6**. Here the objective is to determine the phase of point P with coordinates X0 and Y0. The basic idea is to rotate the position of the point in the clockwise direction until the point is located on the positive X axis. This is done in a manner similar to that of an ADC that uses the successive approximation method. First we try a 180° rotation. If the Y1 coordinate of the resulting point is negative, we have rotated too far. If Y1 is positive (as in the example shown here), we next rotate by 90°, then by 45°, and so on. We keep a running total of all the rotation angles. If we rotate too far in one of these steps, we reverse the rotation. At the end the point is located on the X axis within a specific margin of error, and the total rotation angle corresponds to the original phase.

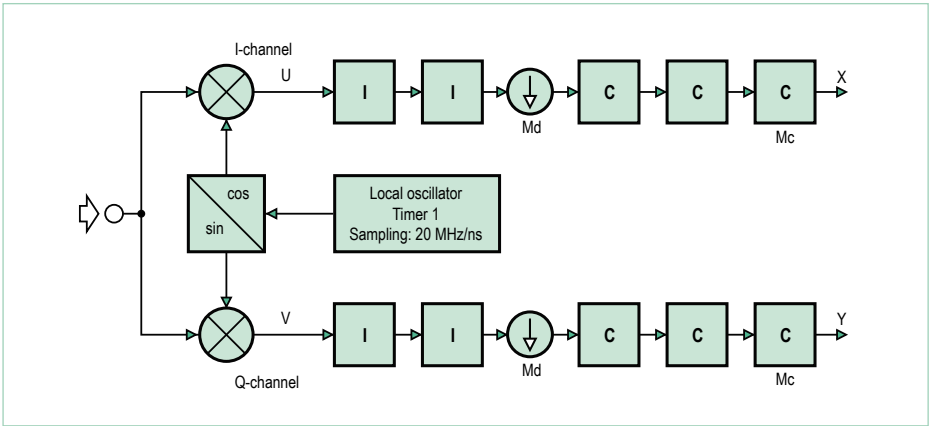


Figure 5. Block diagram of the front end with filters.

Table 1: Receiving frequencies and parameters				
Receiving frequency f	Divisor Ns	Fs (20 MHz/Ns)	f/Fs	Name
60.0 kHz	2250	8.888... kHz	6.75	MSF
75.0 kHz	1800	11.111... kHz	6.25	HBG
77.5 kHz	2000	10.0 kHz	7.75	DCF77
125.0 kHz	1800	11.111... kHz	11.25	Test
162.0 kHz	2500	8.0 kHz	20.25	TDF
198.0 kHz	2500	8.0 kHz	24.75	BBC
648.0 kHz	1875	10.666... kHz	60.75	BBC

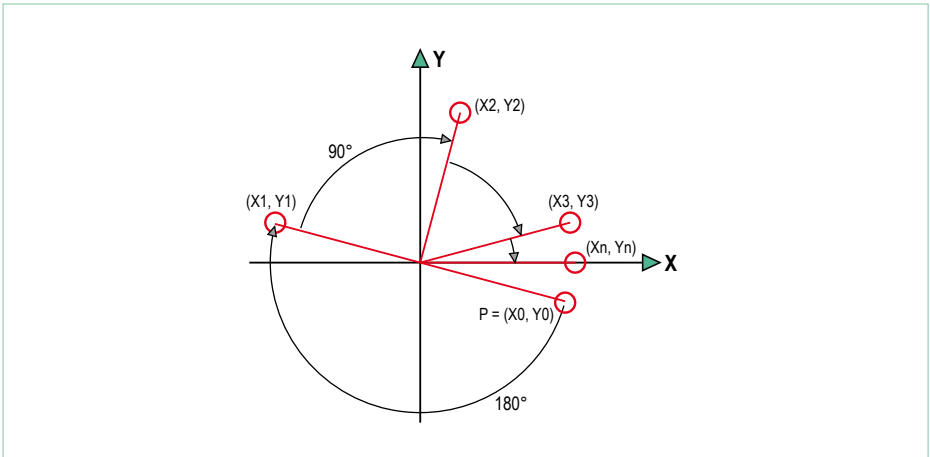


Figure 6. Operating principle of CORDIC rotation.

Listing 4: CORDIC rotation

```

c=iCordicCosTab[k_cordic] ;
s=iCordicSinTab[k_cordic] ;
// rotate (x0,y0) by phi into (x1,y1)
x1=( c*x0+s*y0) / 65536L ;
y1=(-s*x0+c*y0) / 65536L ;

```

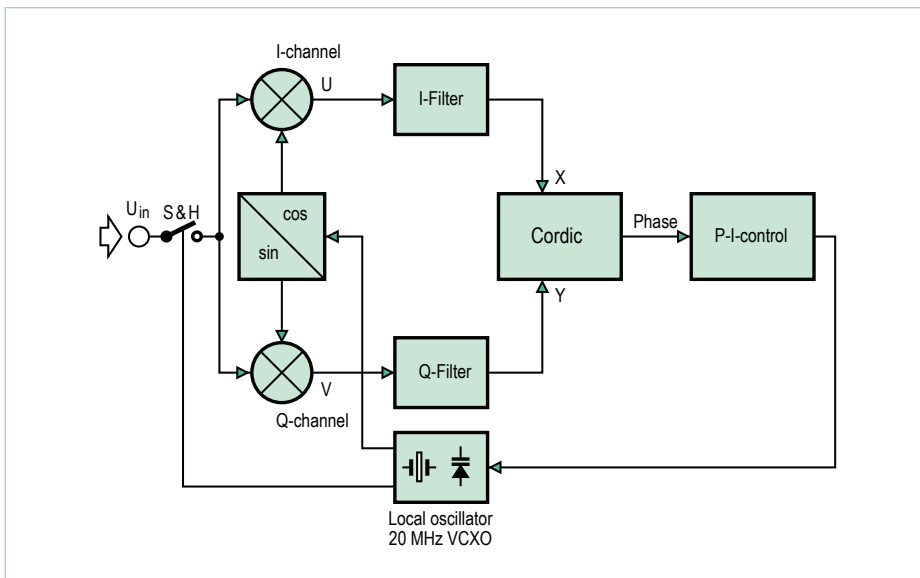



Figure 7. PLL block diagram.

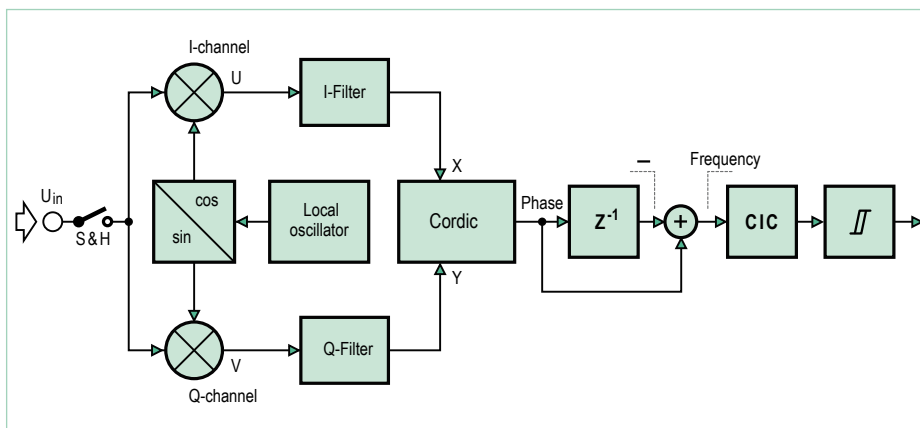


Figure 9. Block diagram of RTTY decoding.

For the implementation, the coefficients of the rotation matrices are multiplied by a factor of 65,536 and stored in a table. For an angle of 22.5° (for example), this gives:

$$65,536 \times \cos(22.5^\circ) = 60,547$$

$$65,536 \times \sin(22.5^\circ) = 25,080$$

The routine for computing the rotation of a point at $(X0, Y0)$ to a new point at $(X1, Y1)$ is shown in **Listing 4**.

This method is very similar to an algorithm called the CORDIC algorithm [6] [7]. After the point has been rotated to the X axis, its X coordinate corresponds to the amplitude, which makes it very easy to determine the amplitude. Our CORDIC routine delivers the angle scaled such that a full rotation (360°) corresponds to exactly 256. This means that range of CORDIC values for a phase range of 0 to 360° is the same as the range of values of a single byte.

High frequency accuracy with a PLL

For this we use the software EXP-Simple-DCF77-RX-V01 [4] to display the amplitude and phase.

If you examine the signal received from the DCF77 time reference transmitter, you will see that its phase drifts slowly. The reason for this is that the frequency of our crystal oscillator is not exactly 20 MHz. You can try to calibrate the oscillator by adjusting the trimmer to minimise the phase drift, but this sort of adjustment will naturally not remain constant for a long time. A better option is to put together a phase-locked loop (PLL). This involves applying the phase signal to a control amplifier and feeding the amplifier output to the control input of the VCXO, as shown in **Figure 8**. If everything is correctly dimensioned and aligned, the

PLL will lock and the signal from the crystal oscillator will be held tightly in phase with the received signal. You can use this to build your own frequency standard by tuning the radio to receive a signal broadcast as a frequency standard.

References:

DCF77, France Inter and BBC

The receiver can be adapted to various transmitters by simply altering a few parameter values. This only requires activating the corresponding options with '#define' statements in the source code. First let's try receiving the DCF77 signal. This signal can be received everywhere in continental Europe. In the western part of Europe, signals from BBC Droitwich (at 198 kHz) and France Inter (at 162 kHz) can also be received. The same approach can be used in other countries with suitable local transmitters.

Putting the PLL into operation

The receiver must be suitably aligned in advance to enable it to lock onto the received signal. Use the following procedure for this purpose. First adjust the active ferrite antenna. To do this, use the signal generator to generate a sinewave signal at the desired frequency. Weakly couple this signal into the antenna by connecting the output signal from the generator through a 1-pF capacitor to the hot end of the tuned circuit. Then adjust the rotary capacitor to maximise the signal level at the output of the active antenna. Of course, the active antenna must be connected to the receiver during this process, to provide it with a source of power. You can use the previously described RMS voltmeter to measure the signal amplitude.

Next, load the program 'EXP-VCXO-PLL-V01', compiled for the right frequency, into the ATmega88. Put jumper JP1 in position A so that the PLL can be adjusted with trim-pot P2. Start by setting P2 to its midpoint. If you now orient the receiving antenna, the lit LED in the LED circle should rotate more or less quickly. Use the trimmer capacitor C8 to adjust the VCXO frequency until the LED point remains stationary or rotates only very slowly. If you now adjust P1, the direc-

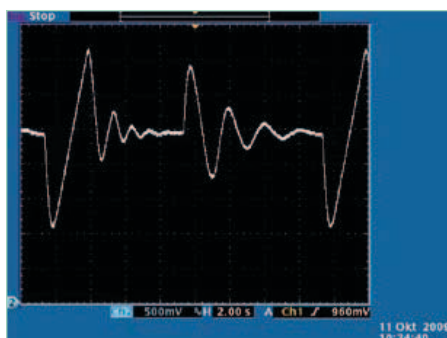


Figure 8. PLL phase response.

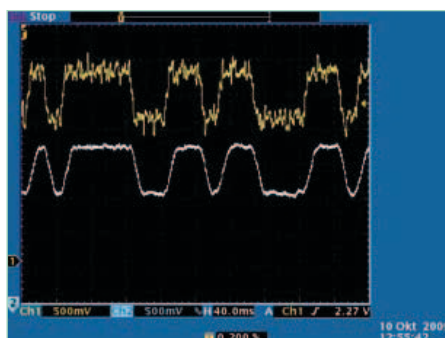


Figure 10. Frequency signal before filtering (yellow) and after filtering (blue).

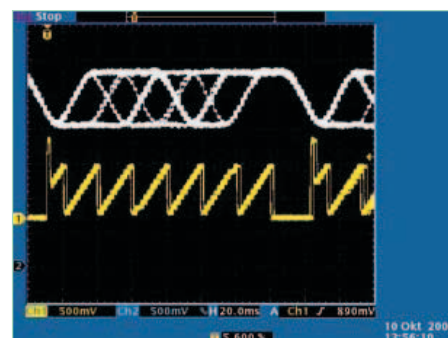


Figure 11. Eye pattern (blue) and clock signal (yellow).

tion and speed of rotation of the LED point should change according to the rotation of P1. If this does not happen, you can try using a different 20 MHz crystal oscillator or slightly modifying the values of C9 and C12. The above procedure ensures that the VCXO can be adjusted over the right range by the 0–5 V control voltage. Now place jumper JP1 in position B to close the control loop. After the circuit is reset, the lit LED should wander back and forth a bit before settling down at a single point. When this happens, the PLL is locked and the 20 MHz oscillator is generating exactly 20 MHz. Incidentally, the two PWM AC outputs of the receiver still deliver the amplitude and phase of the received signal, which can be used as tuning aids. When receiving the DCF77 signal, you can recognise the dip in the amplitude that occurs at a 1-second rate. With the signals from the TDF162 (France Inter) and BBC189 transmitters, you can see the phase modulation.

To check the behaviour of the PLL, we modified the signal generator program to cause it to generate a 125-kHz signal with a step change of plus or minus 1 Hz every couple of seconds. In the oscillograph in **Figure 8** you can see the PLL phase response. The decaying oscillation after each step change shows the PLL locking onto the new frequency.

DDH47: radio teletype at 147.3 kHz

The German Weather Service transmits marine weather reports on 147.3 kHz as radio teletype messages. The messages are transmitted with frequency shift keying (FSK), which produces frequency modulation. After you determine the phase with the CORDIC method, it's relatively easy to determine the frequency by measuring the difference between successive phase values, since the frequency corresponds to the rate of change of the phase. However, this fre-

quency signal is very noisy if the received signal is not very clean. This can be remedied relatively easily by filtering with a CIC low-pass filter. The output signal from the filter is applied to a Schmitt trigger, resulting in the demodulated radio teletype (RTTY) signal.

The block diagram of this arrangement is shown in **Figure 9**. In **Figure 10**, the top trace is the frequency signal immediately after the difference operation, and the bottom trace is the filtered signal — which is a good deal cleaner.

The output signal from the Schmitt trigger is fed to a software UART. The UART performs start-bit detection, serial to parallel conversion, and conversion from Baudot to ASCII code.

Now we tune the ferrite antenna to 147.3 kHz (see [3]) and download the software EXP-DDH47-RTTY-RX-V01 to the SDR microcontroller. The RTTY signal and the bit clock appear at the DAC outputs, and the received signal strength is shown on the LCD.

Figure 11 shows the frequency signal as an eye pattern. Here the oscilloscope trace is triggered by the start bit detection signal, and several curves are shown superim-

posed. If the eyes in the pattern are free from noise and wide open, signal reception is good.

The received characters are output over the serial port of the ATmega88 and can be viewed in a terminal emulator program running on the PC. A short excerpt of the received data is shown in **Listing 5**.

This series will continue in the next issue with a test transmitter and more details on the decoding of various transmitter signals.

(120088-1)

Web links:

- [1] www.elektor.com/100180
- [2] www.elektor.com/100181
- [3] www.elektor.com/100182
- [4] www.elektor.com/120088
- [5] www.ak-modul-bus.de
- [6] www.dspguru.com/dsp/faqs/cordic
- [7] <http://en.wikipedia.org/wiki/CORDIC>

Listing 5: Message received from the German Weather Service

[illegible]

Platino Controlled by LabVIEW (2)

In the previous instalment I showed you how to get started with LabVIEW and LIFA, developing a virtual instrument to blink Platino's LED. This month we will go considerably further, looking inside LIFA, adding a relay board and getting rid of the USB cable that connects Platino to the PC. In the end you will even be capable of monitoring Platino's status on an iPad or Android tablet anywhere in the widely webbed world. Pretty exciting, huh?

By Clemens Valens (Elektor UK/INT Editorial)

Although I wrote it myself, after such a raving introduction it is hard to not feel some pressure. After all, I am promising quite a lot, *n'est ce pas?* So, with space at a premium let's get to work straight away. You may want to have the first instalment handy for reference.

Understanding LIFA

As mentioned in the previous instalment, LIFA employs a serial communications server on the slave device to control it from LabVIEW (LV). Serial communications implies some sort of communications protocol and the one used by LIFA is simple and not very robust. It consists of 15-byte packets going to the slave device with variable length packets returned. The packets sent from LV start with 0xFF and end with a checksum calculated over the payload including the first byte, and excluding of course the checksum itself (**Figure 1**). The second byte holds a command and the contents of the rest of the payload depend on the command. The data returned by the slave device on the other hand is totally freestyle. Most commands return a single byte as a kind of acknowledge, but its value is never checked. Other commands return whatever they feel like, although they will have to respect the number of bytes as defined by the receiving virtual instrument (VI). No checksums, no synchronisation characters, hee-haw, it's a free world. Later on you will see that this freedom creates, let's say, issues.

So how is this protocol implemented? To understand this, let's take a look at the `Digital Write Pin` VI as shown in **Figure 5** of the previous instalment. When in LV you can double-click this block and see what is inside (**Figure 2**). In the upper left-hand corner you see the command `digitalWritePin`, a numeric value in the range of 0 to 255 (`digitalWritePin` equals 3). Just below you have the number of the pin and below that, its value (0 or 1). These three

bytes are combined into an array and passed on to the VI with the glasses (`Send Receive`). The pin number, together with its type (`Digital or Analog`), is checked by the VI with the red dot with the white cross in it (`Check For Pin Out Of Range`). If the pin number is out of range for the slave device, this VI will flag an error. Double click the `Send Receive VI` and you immediately understand why it wears glasses and a pencil: it is of the nerdy type. **Figure 3** shows this intellectual VI. Here the `Arduino` block on the left is the `Packetize VI` that builds the 15-byte packet to send to the slave. The `VISA` block with `abc` written in it does the actual transmitting. Then the `Arduino Wait For Bytes VI` waits for bytes to come back from the slave. Their number is specified by the `Bytes To Read` variable in the upper left corner. If the right number of bytes is received within the specified time, the case structure with `Max Retries` written in it is skipped. The second case structure will in that case read the data into `Read Buffer` (not shown, it is in the `True` case, not in the `False`). If not, errors will be produced.

On the serial server side things are much easier to understand for someone reasonably versed in C. Here, when a 15-byte packet is received, the checksum is verified and if correct the command contained in the second byte is executed. If the command does not need to reply with data (like `digitalWritePin`) it will send a single-byte acknowledge most of the time. If it does have to send data back to the host, it will send it without the acknowledge byte. In LIFA, C stands for Cool.

Extending LIFA

Now that you have some understanding of the inner workings of LIFA it is time to start thinking of adding your own VI. Doing so means that you will have to modify the serial server side too so that it can interact with your VI.

Elektor Projects & Products

- ATM18 Relay Board and Port Expander (October 2008); kits: Elektor Shop 071035-72 & 07103-95
- Bluetooth with the ATM18 (December 2009), kit, Elektor Shop 080948-71
- Bluetooth for OBD-2 (April 2010), BTM222 + PCB, Elektor Shop 090918-71
- Touch LEDs for Arduino (October 2009), PCB, Elektor Shop 090527-1
- Platino versatile board for AVR microcontroller circuits (October 2011), PCB, Elektor Shop 100892-1
- Microcontrollers for Dummies, Arduino for the Enlightened (February 2009), ATmega168 with Arduino bootloader, Elektor Shop 080931-41

Going wireless with Bluetooth, Wi-Fi and Data Dashboard on an iPad or Android tablet*

* (or how to cram as much buzzwords in one subtitle)

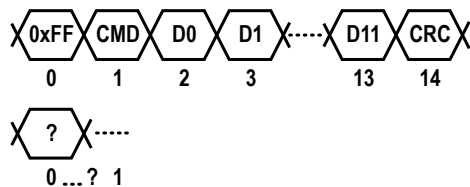
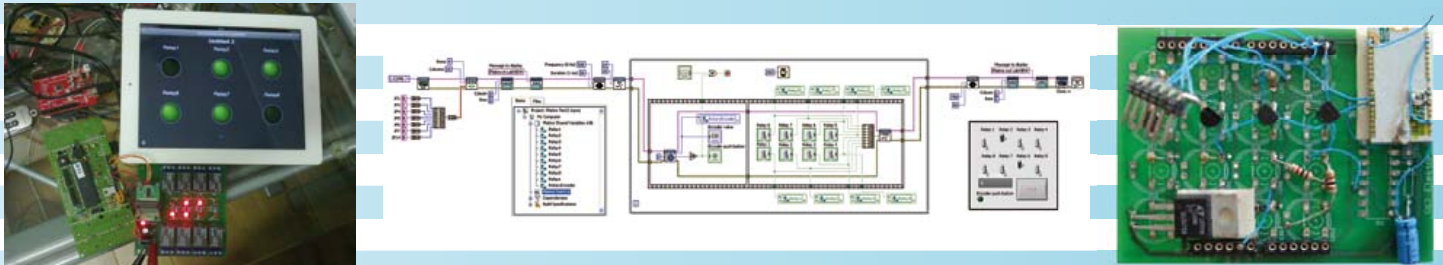


Figure 1. LIFA always sends fixed-format 15-byte long packets to the slave device (top) which will respond in most cases with something to satisfy the receiving VI (bottom).

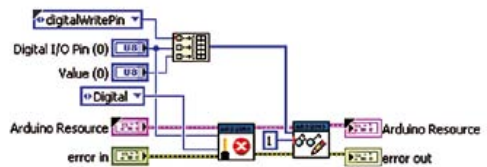


Figure 2. Inside the Digital Write Pin VI. All the clever stuff is done in the blocks labelled 'Arduino'.

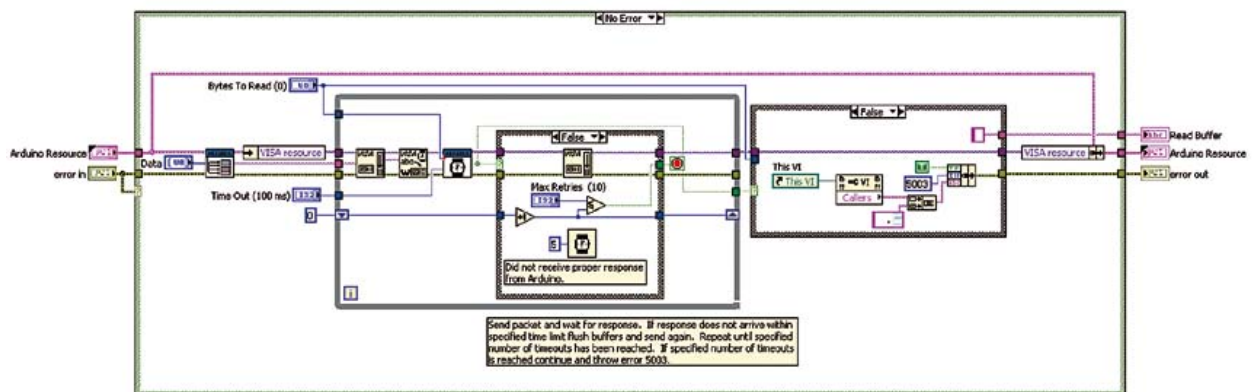


Figure 3. Inside the Send Receive VI. Shown here are the paths that are taken when an error occurs. For normal operation the black case structures are almost empty.

Firmata, a LIFA alternative

As you may have gathered by now LIFA uses a serial server on the Arduino to talk to the I/O. This is not a new idea and actually, instead of developing their own protocol, the LIFA team could have used an existing alternative. The first one that comes to mind is Firmata, which has been included in the Arduino distribution for many years. According to the Firmata website, the official Uno board even comes pre-programmed with Firmata 2.2. Firmata is a MIDI-based protocol (borrowed from the music industry) intended for controlling a microcontroller by a PC and many host implementations can be found on the internet. The protocol is well defined and widely used in robotics and multimedia applications. A VI implementing Firmata exists under the name of labviewduino (<http://code.google.com/p/labviewduino/>).



Figure 4. This is the 8-channel relay board with synchronous serial interface that I want to control from LabVIEW.

As an example I will use this nice 8-channel relay board with serial interface (Figure 4, Elektor Shop # 071035-72) that I have at my disposal. It has a 2-wire custom serial interface that is a bit peculiar so I did the slave side implementation first. I based my code on the original BASCOM example, available at [1] that I ported to C. I will not go into details here, have a look at my code that is included in the download for this article [2].

To use the relay board from within LV two functions are needed, one to set up Platino [3] (Arduino) ports so that it can talk to the relay board and a second function to (de)activate relays at will. The VIs that go with this are similar to LIFA's Set Digital Pin Mode and Digital Write Pin VIs so I used those as templates. Actually, my VIs can be simpler because I don't need the Check For Pin Out Of Range VI. Here is how you do it. If you don't have one in your VI already, put a Digital Write Pin VI in your block diagram. Double click on it to open it, then click File -> Save As.... Now click Open additional copy followed by Continue. Specify a name for your VI and save it somewhere, preferably not in the LIFA folder. Close the Digital Write Pin VI so you will not accidentally modify it. In your new VI click File -> VI Properties. In the window that opens you can set some basic things like the title and the icon for the VI. As Category select General and click the Edit Icon... button to create your own icon. In the Documentation category you can write a short description of the VI, and in the Window Appearance category you can set the VI's title. All the other parameters can be left as they are.

Open the block diagram (Ctrl-E) of your VI (if not already opened) and remove the Check For Pin Out Of Range VI together with its Pin Type constant. Connect the Arduino Resource and error in blocks to the Send Receive VI. Rename the pin and mode constants by double-clicking on them. One last thing now remains to be done: defining a new command. As you will see this turns out to be the hard part.

The easy solution is to reuse a command that you don't need like maybe sevenSegment_Configure (click the Command drop-down list to select it). This will work, but is not really recommended as you may run into conflicts later when you have forgotten all about this

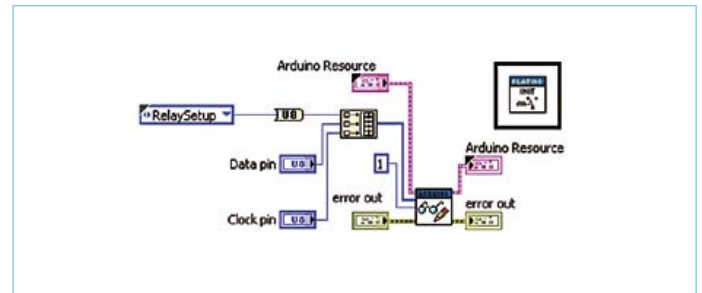


Figure 5. The Relay Init VI is used to define which Platino pins will be used for communicating with the relay board.

hack. Also it is not very user friendly since the name does not correspond to its function.

Another solution is to replace the drop-down list by a byte constant with an unused value. To find out which values are used you can right-click the list and open its properties. On the Edit Items tab the values that are already in use are listed. The last one in my list is FiniteSampleStart which has the value 45. So 46 should be free, right? Well, actually it is, but that's pure luck. Because when you look closely at the serial server code (in the file LabVIEWInterface.pde), you cannot but notice that there are four commands here that are not in the drop-down list. True, they can be configured away by commenting out a define, but it shows that some LIFA developers used the same approach as us, hard-coding commands in the stepper motor VIs without adding them to the commands list. Ooh, that's so gross.

The proper solution is of course to add your own commands to the commands list. I did this by right-clicking the drop-down list and selecting Advanced -> Customize.... In the window that opens you can create a copy of the Type Def (File -> Save As...) which you can edit. Right-click the edit box with setArduinoMode in it and select Edit Items.... Now you can add commands and reorder them. Make sure to add the stepper motor commands too. In your VI replace the original Command drop-down list by your extended copy.

To be totally honest, I do not know if this is the right or recommended way to do things, but it worked for me.

As you can see from Figures 5 and 6 the command arrays that are constructed do not have the same size. You can change the size of an array (and of many other complex objects) simply by resizing it with the mouse. Dragging the bottom line downwards will increase the size, pulling it up makes it smaller.

Good for documentation and ease of understanding of VIs is using labels. Do a right-click on the item for which you want to add a label and select Visible Items -> Label.

Finally, I coded the relay states as bits in a byte using a 1D Boolean array that I cast to a byte.

Tinkering this way I created a whole bunch of VIs to control the peripherals of Platino like the buzzer or the rotary encoders. The most important VI is the Platino Configure VI that lets you setup the LCD and the solder jumpers.

LIFA issues

As mentioned before, LIFA has some quality issues that you may want to be aware of. I already mentioned the hard-coded stepper motor commands and if the LIFA development team continues extending the library in such a manner, we will be in for trouble.

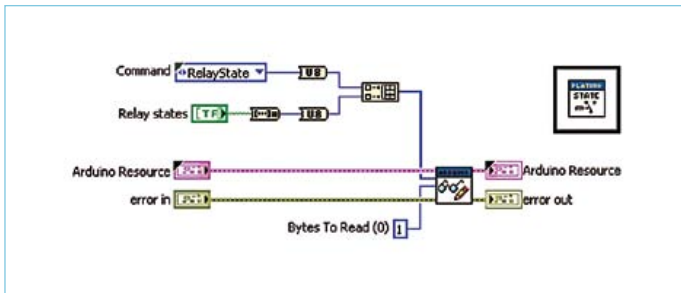


Figure 6. The `Relay State` VI allows toggling the state of the relays. Each relay takes up one bit of the command's data byte.

But there is more.

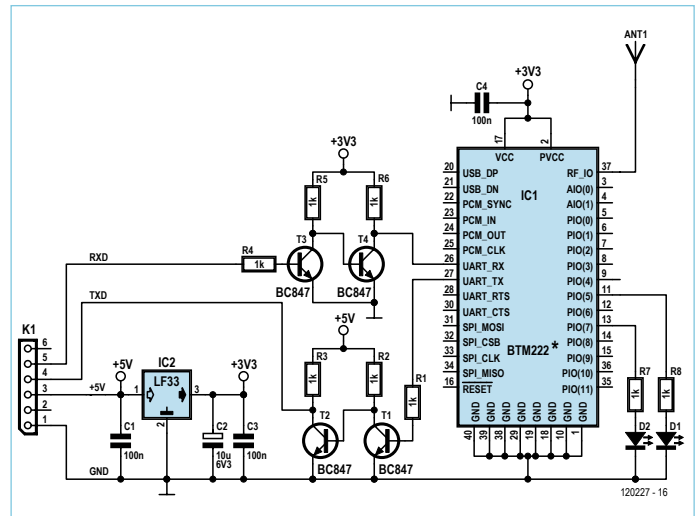
When you look closely at the commands that pass values that do not fit in one byte you will notice that they do not do this in a consequent way. Some VIs will use big-endian formatting where others prefer little-endian. This is of course confusing and may quickly lead to errors.

On the serial server side the main problem is sloppy coding. This not only leads to wasting precious program memory, it is also rather hard to maintain. Also, when you compile it you may see warnings (if you activated them in the Arduino IDE preferences) that can be fixed easily. The commands are not implemented using defines with understandable names but instead coded directly as hexadecimal values in a large illegible switch-case structure. For my own use I decided to recode this properly and while doing this I added configuration options allowing me to leave out the bits I didn't need, saving lots of program memory.

Finally I came across a difficult issue probably due to the inherent parallelism of LabVIEW and the weak communication protocol. When I tried to create a VI that would display the value generated by a rotary encoder and allow setting of the relays at the same time I noticed that the respective VIs did not receive the right data. It seemed that one VI was receiving the data intended for the other. I finally managed to fix this by adding a serial port flush to `Send Receive` VI. You can see it in **Figure 3**, it is the `VISA` block with a little microwave oven and a Wii game console in it (funny icon, isn't it?), just left of the one with `abc` written in it. This one was added by me and is not part of the official LIFA distribution. What it does is flushing the serial input buffer right after sending a command to Platino. Since Platino will handle only one command at a time this flush should insure synchronisation between LV and Platino. An extra sync byte added to the protocol would have been useful here.

Cutting the umbilical cord

I hate wires and cables. They are always too short; never have the right connectors at the end and forever create spaghetti knots. Today there are solutions to get rid of some of those cables and one of them is called Bluetooth. My computer has Bluetooth (BT), and if yours doesn't just stick a BT dongle in it. Adding BT to Platino is very easy if you only need a serial cable replacement. In Elektor we have used several Rayson BT modules that can do this. They are inexpensive and badly documented, but that doesn't stop me [4]. To connect a BTM220 (BTM222, BTM112, etc.) you only need a level shifter for the RX and TX signals because it is a 3.3 V module. We already showed you how to do this in Elektor [5], but you can use **Figure 7** as a reminder. I quickly built an extension card in Arduino



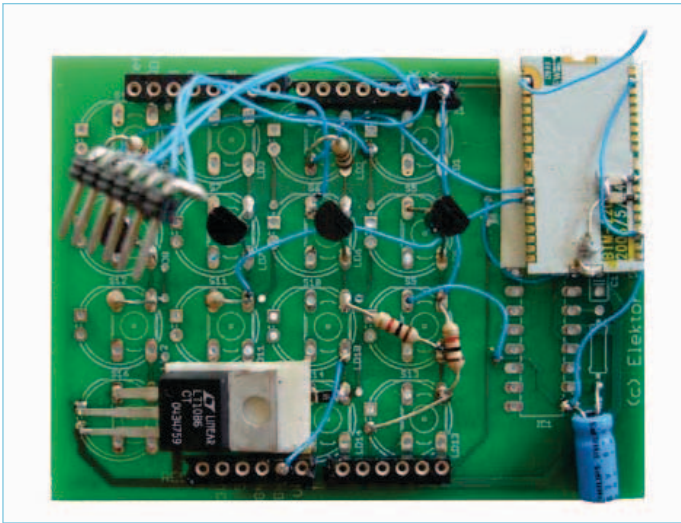


Figure 8. The Bluetooth shield I cobbled together on an old board with the Arduino form factor (Elektor ref. 090527-1, October 2009). You can also use the OBD-2 NG BT module published in April 2010 (Elektor ref. 090918-71). The dangling connector is for connecting the FTDI USB serial cable to configure the module. The antenna wire is supposed to be 31 mm long.

tion you have to configure the BT connection on the PC as a virtual serial port. This is pretty straightforward on Windows — I don't know about other operating systems. The last step now is to select the new virtual serial port in your VI as the one to use by the `Arduino Init VI`.

There you go. As soon as you start your VI it will first (automatically) establish the wireless link before doing its normal business and everything should work exactly the same as with a wired connection. Platino can now move around unhindered by cables while staying in touch with LV.

Going World Wide

Ever since you bought that tablet computer because you wanted to own one, you are desperately looking for things to do with it. Here

is an idea. National Instruments (NI) has released a free application for Android and iPad tablets called Data Dashboard. With this app you can visualise shared variables that are published by your VI. For now you cannot control anything with Data Dashboard, but maybe NI will add that functionality in a future version. So how do you publish a variable? Here is how.

First of all you have to use a project. You cannot do this simply in a VI, the VI has to be part of a project. Create an empty project, click right on **My Computer**, then click **Add -> File...** and navigate to your VI in order to add it to the project. Double click the VI to open it and then open its block diagram view.

To add a shared variable again do a right-click on My Computer and select New -> Variable. In the Shared Variable Properties window that pops up give the variable a name and make sure that the Variable Type is set to Network-Published. As Data Type select the type that you need. But be careful here as not all data types are supported by Data Dashboard, so you'd better stick to Double or Boolean. More types may be added in the future.

When you close the window you will see that the newly created variable was added to a new library in your project. You can rename the library if you like. To add the shared variable to your VI, simply drag it to the block diagram (or to the front panel if you need it there too) and drop it. Since you can only monitor this variable you have to change its **Access Mode** to **Write** (right-click on it) so that you can connect it to the signal of your choice.

Add as many shared variables as you need. Once you're done, you will have to deploy them. Normally this is done automatically when you start the VI, but it does not hurt to do it manually too. It is done by right-clicking the new library in your project and then selecting **Deploy All**. If all is well you will briefly see a **Deploy Progress** window that you will see again when you launch the VI.

Your VI is now ready (**Figure 9**) and sharing variables, the next step is to setup Data Dashboard.

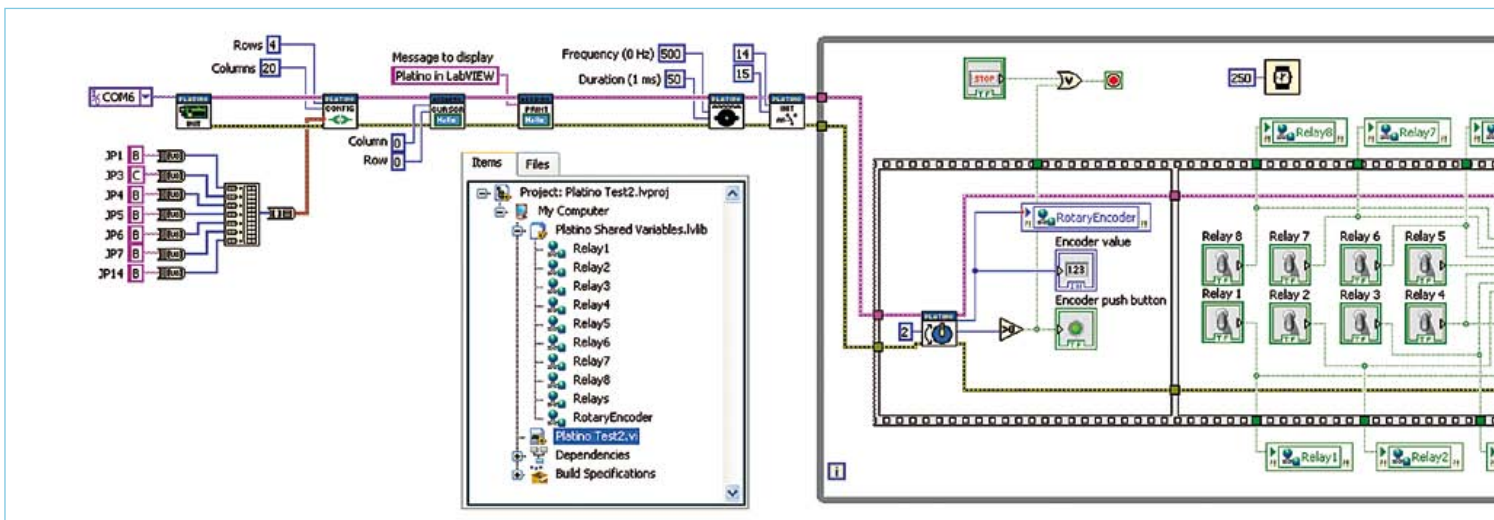


Figure 9. The relay controlling VI including shared variables accessible from Data Dashboard.



Figure 10. The server selection window in Data Dashboard on an iPad. If your server is listed, tap it, if not tap Connect to shared variable.

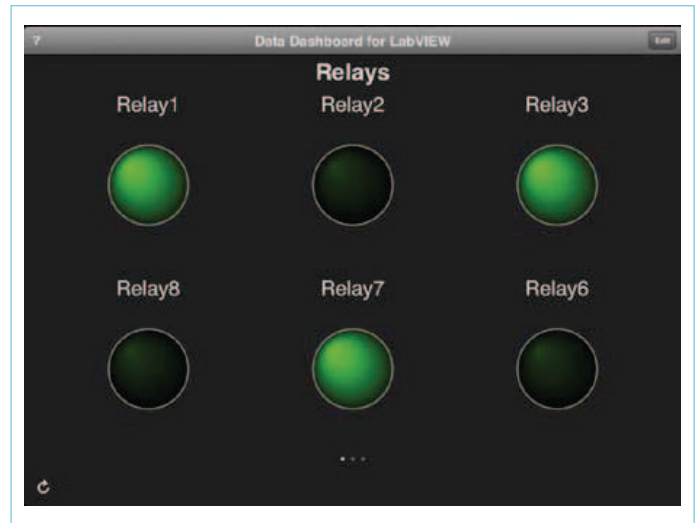


Figure 11. Data Dashboard showing the status of six relays. So where are relays 4 and 5? They are on the next page, because you can have no more than 6 indicators on one page. I wanted the same layout as the LEDs on my relay board so relays 4 and 5 fell off this page.

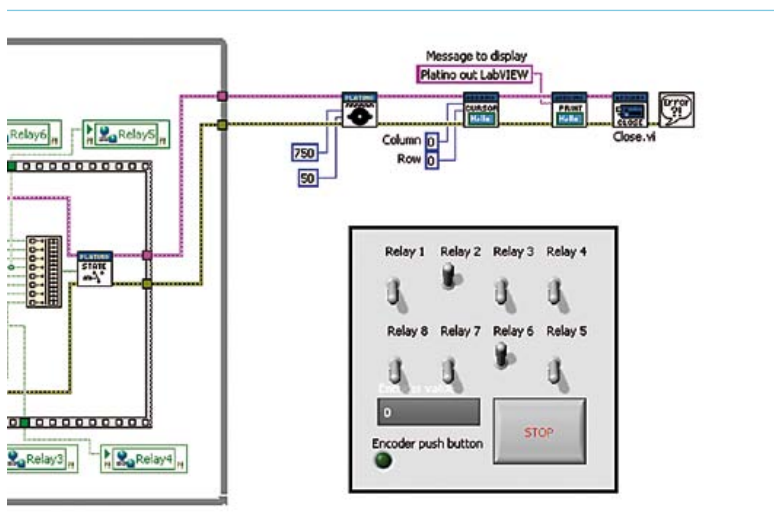
Get the Data Dashboard app from the market that suits you best. I used an iPad so I downloaded it from the Apple Store. Launch the app and select a page layout (1, 2, 4 or 6 indicators per page). Give the page a name (tap *Untitled 1*), then tap *Add* in the indicator of your choice. This will bring up the *Select a server* window (Figure 10). Since you don't have a server yet, tap *Connect to shared variable...* and enter the server's name or IP address (192.168.0.2 in my case) and tap *Connect*. (If you don't have a server you can try the app with the *Demo variables*.) If the server was found, you will now see the *Select a variable* window listing the shared libraries available on the server. You will probably see the *System* library that you get as soon as you install LabVIEW. Tap your VI's library and then tap the variable that you want to display. You will be presented with a few options for the

indicator. A numeric variable can be shown as a string, a gauge or a chart; a boolean can be a string, an LED or a chart. When you pick a chart or a gauge you have to enter the minimum and maximum values too.

Once you have set up all the indicators you can tap *Run* to start monitoring (Figure 11). Of course the VI should be running too. In case of connection problems the indicators show a yellow warning triangle.

That's it, now you're all set to let Platino ride around on a wirelessly controlled robot communicating over Bluetooth with a VI running on your laptop, collecting data that you can monitor on your tablet from anywhere in the world. As I said in the introduction: pretty exciting, huh? Maybe in a future article I will introduce LabVIEW web services to take the concept even further.

(120227-1)



The front panel and the project tree are also visible.

Internet Links and References

- [1] 8-channel relay board with synchronous serial interface: www.elektor.com/080357
- [2] Code examples for this instalment: www.elektor.com/120227
- [3] Platino: www.elektor.com/100892
- [4] Experiments with Rayson Bluetooth modules: <http://elektorembedded.blogspot.com/2010/08/rayson-btm222-btm112-blue-tooth-modules.html>
- [5] Bluetooth with the ATM18: www.elektor.com/080948
- [6] Bluetooth for OBD-2: www.elektor.com/090918

Electronics for Starters (6)

Flip-flops

To understand the basics of electronics, you have to go beyond high-level block diagrams — now and then you need to look at the details inside the blocks. For example, a microcontroller consists of a large number of functional blocks, each of which is composed of just a few transistors. The best way to learn how these subunits work is to conduct simple, hands-on experiments.

By Burkhard Kainka (Germany)

On or off, one or zero: welcome to the world of digital logic! Along with analogue tasks, transistors can also be used for digital tasks. In the past there were even full-fledged computers built entirely from discrete transistors. One of the most important basic digital circuits is the flip-flop. Even a single flip-flop can be put to good use in practical applications.

The flip-flop

A flip-flop is a circuit with two stable states. Flip-flops are important basic elements of digital computer technology, particularly for use in counters and memories.

Flip-flop circuits use positive feedback of an in-phase, amplified signal. This can be implemented using two inverting amplifier stages (Figure 1). As each stage inverts the signal, the input and output signals of the overall circuit are in phase. The feedback from the output to the input causes the output signal to go to one of two states. A rising voltage on the output, for example, is amplified by the circuit and drives the out-

put voltage even higher. As a result, the circuit switches to the fully 'on' state. In the other direction, a falling output voltage causes the output to be quickly switched to the 'off' state.

The amplifier can be built as a two-stage, directly coupled transistor circuit (i.e. without coupling capacitors). Each common-emitter stage (Figure 2) inverts its input signal. This simple circuit is effectively a bistable flip-flop, which means that the output voltage can be either low (nearly 0 V) or high (nearly the same as the supply voltage), and it remains in the given state for an indefinite length of time. The state can only be changed by some sort of external action.

When the output voltage is low, the left-hand transistor does not receive any base current and is therefore cut off. As a result, its collector voltage is high and the right-hand transistor receives full base current, causing it to be driven hard on. This causes the output voltage to stay low. When the output voltage is high, the situations of the two transistors are exactly reversed. It is

impossible to predict which state the circuit will assume after being switched on — it's simply a matter of chance.

RS flip-flop

Now let's add a pair of LEDs to our circuit, along with two pushbutton switches that can be used to change the state as desired (Figure 3). After switching on the power, you will see that one of the two LEDs is lit. You can't say in advance which one of the two will light up. Which way the circuit goes when it is powered on (i.e. which state it assumes) usually depends on the difference in the current gains of the two transistors. If they happen to have identical characteristics, noise (which is always present in electronic circuits) plays a role. Accordingly, it may happen that the circuit sometimes ends up in one state after being switched on, and sometimes in the other state.

However, it's possible to set the circuit to either state as desired. To do so, simply press one of the two pushbuttons, each of which shorts out the base current of the associated transistor. This circuit is called a reset/set (RS) flip-flop.

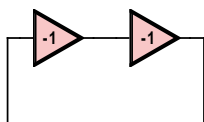


Figure 1. Functional block diagram of an amplifier with feedback.

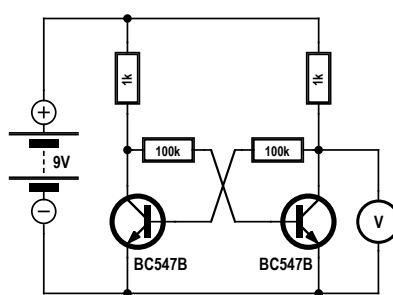


Figure 2. A bistable flip-flop with two transistors.

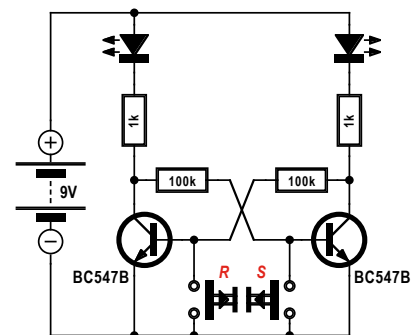
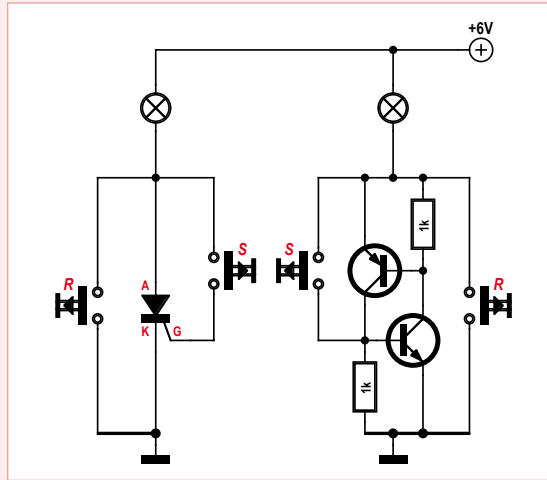


Figure 3. An RS flip-flop.

Thyristors

Thyristors are bistable switching devices with three electrodes: a cathode (K), a gate (G) and an anode (A). The gate electrode is used to trigger (switch on) the thyristor, which remains conductive until the circuit is interrupted. The structure of a thyristor is similar to that of a transistor, but it has four semiconductor layers (NPNP). The gate electrode operates in a similar manner to the base of an NPN transistor. If the gate current rises above a specific threshold value, the thyristor is triggered and starts conducting. It remains conducting until the current stops



flowing through the device. This can be done by switching off the supply voltage or by briefly shorting out the thyristor. Another technique that is often used is to operate the device with an AC voltage. In this situation, the thyristor stops conducting each time the voltage passes through zero.

The circuit diagram here also shows an equivalent circuit with bipolar transistors. This equivalent circuit can also be switched on (triggered) or off in the same manner. Both circuits can be used in the same way as an RS flip-flop.

An RS flip-flop can be used as a 1-bit data memory. It can save states such as 'red' of 'green' (if you use LEDs with these colours), 'on' or 'off', 'yes' or 'no', etc. You could use this sort of device at home to leave a message, such as "Back right away" or "Out for a while". Your message remains present until it is changed.

Reset buttons and reset inputs are commonly found on computers and microcontrollers. This is hardly surprising, since complex systems of this sort contain a large number of flip-flops, some of which are used to store data. When the power is first switched on, all static flip-flops initially assume a random state. To bring order to this chaos, you need a reset function. A short reset pulse is all it takes to set everything nicely to zero. Now the work can begin.

Incidentally, modern microcontrollers use MOSFETs instead of bipolar transistors,

and things are even easier with MOSFETs. An RS flip-flop using two BS170 MOSFETs (Figure 4) can manage without the base resistors needed by the version with bipolar transistors.

Triggering and clearing

A flip-flop can be built with an NPN transistor and a PNP transistor wired as shown in Figure 5. Here the collector current of each transistor is the base current of the other one. As a result, both transistors are either cut off or conducting. After power is switched on, the circuit is initially in the non-conducting ('off') state.

Briefly actuating the switch puts the circuit in the conducting ('on') state. The transistors remain in the conducting state until the supply voltage is switched off. This circuit therefore acts the same way as a thyristor (see inset). Incidentally, the capacitor in the circuit prevents the circuit from accidentally

triggering by itself when the supply voltage is applied.

Monostable flip-flops

In many situations what is wanted is a flip-flop circuit that changes to a different state for a defined period instead of indefinitely. For example, this could be used to build a timer that is triggered by a pushbutton and switches off automatically after a certain time. This behaviour can be achieved by including a capacitor in the feedback path. The capacitor starts charging when the timer is triggered. When it is fully charged, no more current flows in the feedback path and the circuit returns to the stable quiescent state. The timeout period ('on time') of the circuit shown in Figure 6 is approximately 10 seconds.

Schmitt trigger

A Schmitt trigger is a circuit that converts a variable input signal into two distinct states

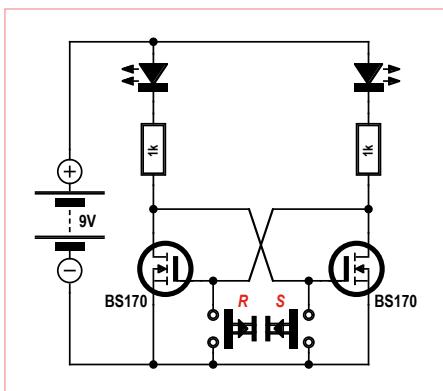


Figure 4. An RS flip-flop with MOSFETs.

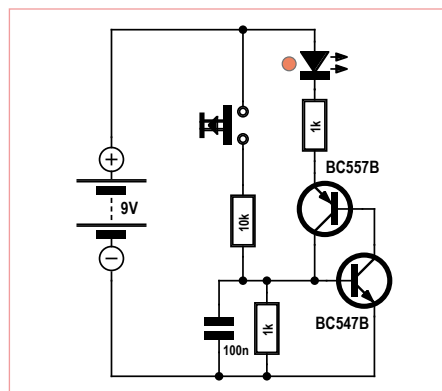


Figure 5. A bistable circuit with complementary transistors.

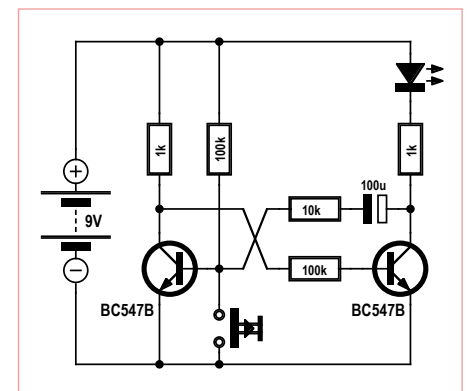
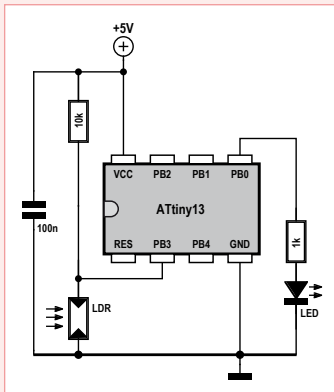


Figure 6. A monostable flip-flop.

Twilight switch



It's quite easy to implement a Schmitt trigger function using a microcontroller. You simply measure the input voltage and compare it with pre-defined threshold values. The output is either switched on or switched off, depending on the results of these comparisons. The two switching thresholds are defined independently. This gives you complete control over the amount of hysteresis.

In addition, you can build a defined delay into the program. A one-second wait loop also helps prevent undesirable switching jitter.

We implemented a twilight switch using the Tiny13 and a few additional components.

```
'Twilight switch
$regfile = "attiny13.dat"
$crystal = 1200000
$hwstack = 8
$swstack = 4
$framesize = 4
Dim U As Word
Config Adc = Single , Prescaler = Auto
Start Adc
Config Portb = 1          'Output B.0
Do
  U = Getadc(3)
  If U < 400 Then Portb.0 = 0
  If U > 600 Then Portb.0 = 1
  Waitms 1000
Loop
End
```

(High or Low). It has two threshold levels separated by a hysteresis zone. For example, with threshold levels of 2 V and 1 V, the output changes to the 'off' state when the input signal rises above 2 V and remains in that state until the input signal drops below 1 V. The current state remains unchanged as long as the signal level remains in the hysteresis zone.

The classic Schmitt trigger circuit (**Figure 7**) employs feedback over a common emitter resistor. The thresholds and the amount of hysteresis can be set as desired by selecting suitable resistor values.

As a diversion, you can try a little RF experiment with this circuit. Connect a length of wire to the input to act as an antenna, and

then adjust the potentiometer very close to one of the switching points. Now flip a light switch. You may hear some static on the radio, and at the same time the circuit will be triggered and its state will change. Here the Schmitt trigger effectively acts as a broadband radio receiver, with the light switch acting as the associated radio transmitter.

An illustrative example of a Schmitt trigger application is a twilight switch (**Figure 8**). Here the idea is to switch on a lamp when it gets dark outside. An important consideration is that the lamp should not flicker near the switching point. This means that the circuit should switch off only after the light level rises significantly. In other words,

there must be some hysteresis between the two switching points.

The voltage at the input of the Schmitt trigger here depends on the resistance of the LDR. This resistance increases with decreasing ambient light level, which causes the LED to switch on. When the ambient light level rises, the LED is switched off. There is noticeable hysteresis between the two switching points. It should be sufficient to prevent the circuit from responding to the flickering of artificial lighting.

Simplified Schmitt trigger

A simpler implementation of a Schmitt trigger is shown in **Figure 9**. Here two NPN transistors in common-emitter configuration are directly coupled. An additional

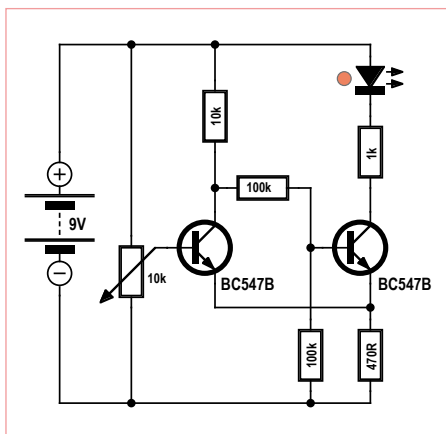


Figure 7. A classic Schmitt trigger.

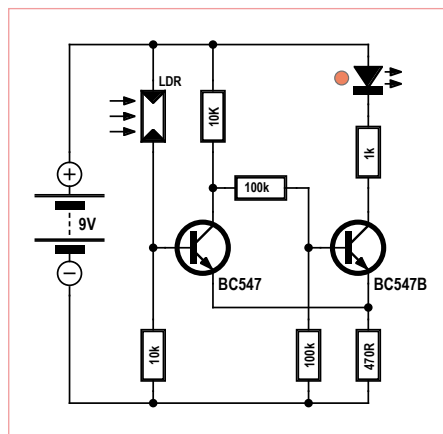


Figure 8. A twilight switch.

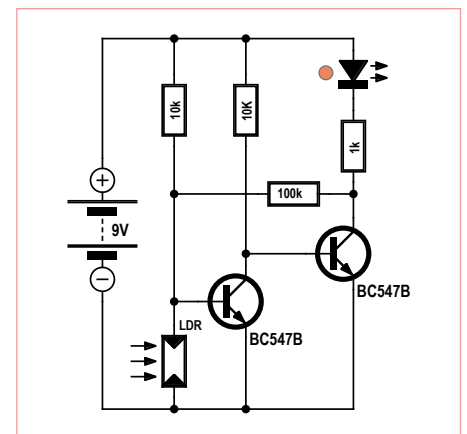
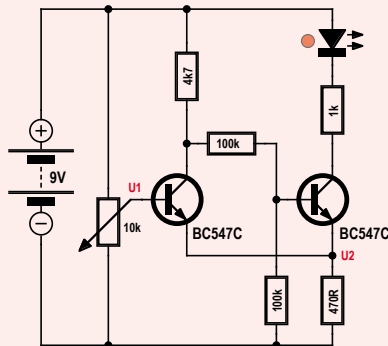


Figure 9. A simplified Schmitt trigger.

Quiz

The circuit diagram shows the Schmitt trigger from Figure 7 with slightly different component values and two test points. The transistors are C versions (with the highest possible current gain), so the base currents can be ignored in your calculations. Voltages U1 and U2 are both measured to ground (i.e. relative to the minus terminal of the battery). The potentiometer should initially be adjusted fully anti-clockwise (wiper at the bottom end). As a result, the left-hand transistor is cut off. A high voltage is present on its collector, so the right-hand transistor receives enough base current to drive it fully on. In the 'on' state a voltage U2 is present across the common 470-Ω emitter resistor, due to the sum of the two emitter currents. Next we raise U1 until the circuit changes state. Voltage U2 is now less lower before, because less current flows through the left-hand transistor when it is conducting than through the right-hand transistor when the latter is conducting. The difference between the collector currents produces the hysteresis. Note: It's easier to quickly build the circuit and make measurements on it than to calculate everything exactly.



1) U1 = 0 V. The LED is lit. What value do you measure for U2?

- A) Approximately 0.47 V
- B) Approximately 1 V
- C) Approximately 2.3 V

2) U1 is increased slowly. At what voltage U1 does the output change state?

- D) Approximately 2.9 V
- E) Approximately 4.5 V
- F) Approximately 6 V

3) U1 is decreased slowly. At what voltage U1 does the output change state?

- G) Approximately 1.4 V
- H) Approximately 2 V
- I) Approximately 2.5 V

If you send us the correct answers, you have a chance of winning a **Minty Geek Electronics 101 Kit.**

Send you answer code (composed of a series of three letters corresponding to your selected answers) by e-mail to **basics@elektor.com**.

Please enter only the answer code in the Subject line of your email.

The deadline for sending answers is June 30, 2012.

All decisions are final. Employees of the publishing companies forming part of the Elektor International Media group of companies and their family member are not eligible to participate.

The correct solution code for the quiz in the April 2012 edition is 'CDH'. Here are the explanations:

Answer 1: Unfortunately, there were three decimal-place errors in the first question. We apologise for these errors.

Instead of: A) 100 Ω B) 47 Ω C) 22 Ω
the potential answers should have been:

A) 10 Ω B) 4.7 Ω C) 2.2 Ω

$$R_x = 0.7 \text{ V} / 0.35 \text{ A} \quad R_x = 2 \Omega$$

Result: 2.2 Ω; answer C is the closest (the current is 10% less than the allowable current).

Note: We ignored the answer to this question, due to our errors in the question.

Answer 2: The voltage over the three LEDs together is 10.2 V.

$$\begin{aligned} \text{Efficiency} &= U_{\text{total}} / U_{\text{useful}} \\ &= 10.2 \text{ V} / 12.6 \text{ V} \\ &= 81\% \end{aligned}$$

Option D is correct.

$$\text{Answer 3: } U_{\text{CE}} = 14 \text{ V} - 10.2 \text{ V} - 0.7 \text{ V} = 3.1 \text{ V}$$

$$P = U \times I$$

$$R = 3.1 \text{ V} \times 0.35 \text{ A}$$

$$P = 1.085 \text{ W}$$

Option H is therefore correct (approximately 1 W).

resistor from the output to the input provides the necessary feedback for the switching hysteresis.

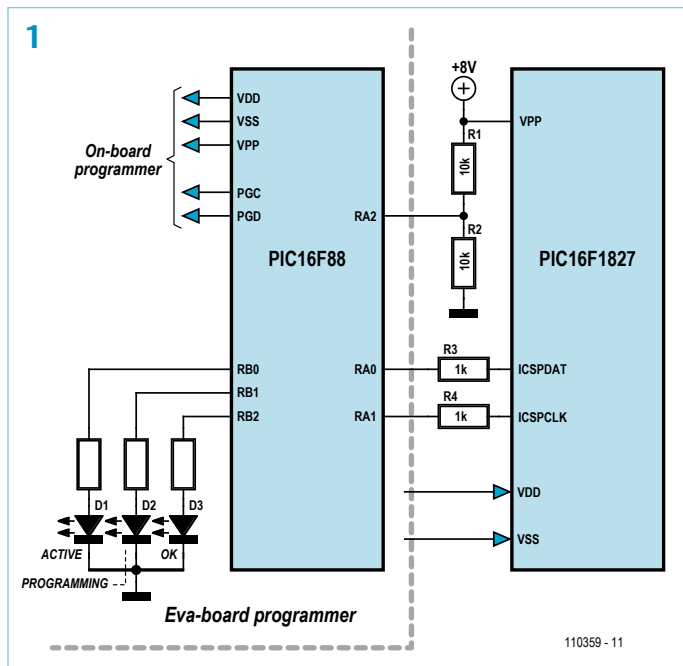
For this experiment we again use the LDR as a variable resistor. However, in this case the LED switches on when the light level rises

and switches off when the light level falls. This circuit switches cleanly, even with a slowly decreasing light level. It has the typical Schmitt trigger characteristic of converting a gradual change into a step change. The sensitivity of the circuit can be adjusted over a wide range to suit various lighting condi-

tions by modifying the voltage divider at the input. With a 10-kΩ fixed resistor, it switches at a relatively high light level (e.g. close to a lamp). With a 100-kΩ resistor, it is suitable for sensing typical light levels in residential rooms.

(120006-1)

PIC Programmer for Emergencies



Instructions

- Compile the program, so that a hex file for the PIC16F1827 is generated.
- Convert this ihex file with ihex2pic (available via [1]).
- Open SimpProg.asm in MPLAB and check whether the correct 'include' file is called.
- Place the PIC16F88 in the powered-down evaluation board and then connect the PIC16F1827 according to the schematic of **Figure 1**.
- Program the PIC16F88 using the programmer supplied with the evaluation board.
- When programming is complete LED D1 will turn on. The 8-V programming voltage can now be switched on.
- LEDs D2 and D3 will now also turn on. Wait until both LED D1 and D2 turn off. If all goes well LED D3 will still be on; otherwise a programming error has been detected.
- Switch off the 8-V programming voltage and the power supply voltage to the evaluation board. The PIC16F1827 is now ready.

(110359-1)

[1] www.elektor.com/110359

By Elbert Jan van Veldhuizen (Netherlands)

The author had bought a number of PIC microcontrollers from a new range with an enhanced instruction set (PIC16F1827). However, this type of controller was not recognised by the available programmer and the necessary software update was taking its time. If you have access to an evaluation board that contains a programmer, then, using a trick, it is still possible to program new controllers very easily. This requires only four resistors, an external power supply and an additional PIC which can be programmed using the existing board.

The author had a PIC16F88, which was recognised by the programmer. A small program was made for this PIC16F88 (about 500 words) to program the PIC16F1827 (available from the Elektor website [1]). Another requirement is to have a program running on a PC that converts the ihex file for the PIC16F1827 into an include file for the PIC16F88. This data will then be placed in the remaining program memory (about 3,500 words) of the PIC 16F88 and subsequently read out as raw data.

Three LEDs on the evaluation board are used to indicate the status of the programming operation. When LED D1 is lit, the controller is ready to program. The user can then apply the 8-V programming voltage to the PIC16F1827. LEDs D2 and D3 will then come on indicating that programming is in progress. LED D3 goes out if a programming error is detected. LEDs D1 and D2 both turn off when programming is complete. If there have been no errors then LED D3 will remain on. The 8-V voltage and the power supply voltage to the evaluation board can now be removed and the PIC16F1827 is ready. Resistors R1 and R2 ensure that the PIC16F88 can detect when the programming voltage of 8 V is present. Resistors R3 and R4 are not really necessary, but serve as protection should both processors, as a result of a programming error, both start to transmit data at the same time (and effectively will be shorted together), or if the IC is not connected correctly.

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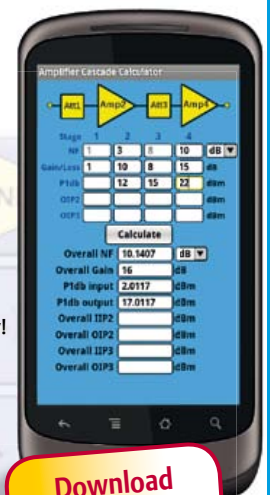
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2-Wire Interface for Illuminated Pushbuttons

Cut down on cabling to improve reliability

By Klaus Jürgen Thiesler (Germany)

Reducing the number of interconnections in a design improves system reliability. There are fewer problems of unreliable contacts and cable failures. This design shows how you can get away with just two wires instead of the more usual three when connecting an indicator pushbutton.

Engineers are no friends of a wiring rat's nest. More cables means more connections means more chance of an unreliable system. For this reason the trend is for serial in preference to parallel interfaces, even when the serial interface requires processing power to reformat information. The same is true for connections between a microcontroller system and a remote user-interface: the fewer the wires the better. With this in mind the author set about optimising the interface to a common type of input device: a pushbutton with an LED illuminator/indicator. The resultant circuit uses just two wires instead of the more usual three. As more switches are needed, the benefits begin to add up.

Cutting down

When connecting an indicator pushbutton to a microcontroller it is usual to use one wire from the pushbutton contact to an input port pin and another from an output port to drive the LED. Both use a common earth return making three wires altogether. To reduce the wiring to just two wires it is necessary to wire the LED in parallel to the pushbutton contacts as shown in the left hand side of the diagram in **Figure 1**. In principle the LED can be connected in series with the contacts but a normally-closed contact would be necessary (or the normally-closed contacts of a changeover pushbutton) otherwise the LED cannot light without the button being pressed. Parallel wiring is however the simplest configuration.

The trick used here is to always have current flowing through the LED, even when it is not illuminated (and the pushbutton not pressed). The LED in this state passes a current level of just a few tens of microamps to create a forward voltage drop but not sufficient to produce any visible light. When a few mA are passed through the LED it lights and the forward voltage drop increases slightly but always remains between 1.2 V and 1.9 V until the pushbutton is pressed which shorts out the LED. The resultant voltage changes can be processed. The LED goes out when the pushbutton is pressed to give a visual indication of a key press.

The circuit

R1 provides a continuous low level current through the LED (around 20 μ A at $V_{CC} = 3.3$ V). To make the LED light up the microcontroller output port pin Port.1 is switched to Low. In this state T1 operates as a simple constant current source with a voltage drop across R3 of approximately 1 V. Subtracting the V_{be} 'ON' voltage of T1 leaves around 0.33 V across R2 which gives a constant current of the order of 10 mA through R2 and the LED. When the Port.1 pin is High the LED does not illuminate.

For the pushbutton the voltage divider ratio ensures that transistor T2 conducts when the voltage at K2.1 exceeds 0.85 V. In its quies-

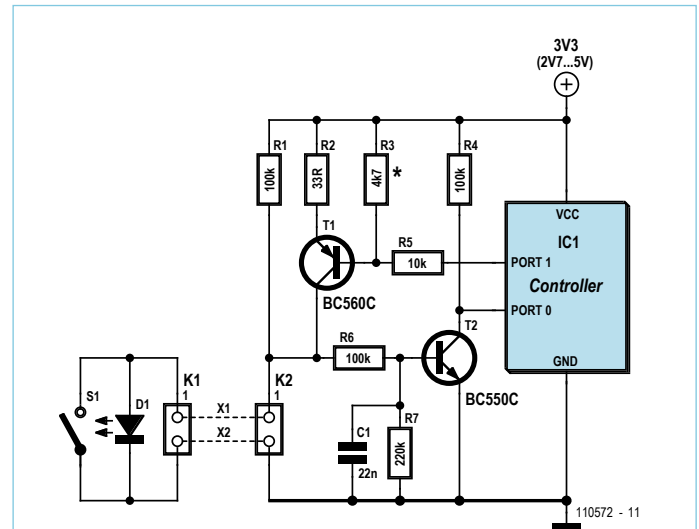


Figure 1. Circuit of the two-wire interface.

cent state the voltage level at the controller input Port.0 will be Low. When S1 closes, the voltage across the LED drops to zero turning off T2 and allowing pullup resistor R4 to take input Port.0 logic High. The low-pass filter formed by R6 and C1 suppresses any interference picked up on the wire X1. The quiescent current of the complete circuit is the sum of the current through R1 and R4 and amounts to around 50 μ A.

Adaptations

Many of the more modern microcontrollers can operate with a supply voltage of 3.3 V or less. There are however still many new and existing designs that use microcontrollers with a $V_{CC} = 5$ V. Fortunately the circuit is designed so that only a single resistor needs to be changed for different values of supply voltage: with a supply of 2.7 V $R3 = 8.2$ k Ω while at 5 V $R3 = 2.7$ k Ω . Where an even lower supply of 2.2 V is used $R3 = 10$ k Ω and T1 should be swapped for a PNP transistor with a particularly low value of V_{CEsat} . A good example would be the FM718.

Other transistor types can be substituted but take care that they are types with high current gain. The majority of microcontrollers have configurable output port pins. A totem-pole or open-collector output type can be used at Port.1. When using a port input with a built-in pullup resistor for Port.0 resistor R4 can be omitted.

The savings increase with the number of pushbuttons used: only six wires are needed to connect five illuminated pushbuttons (one wire to each pushbutton plus a common ground). This represents a saving of around 40 % in cabling costs. The extra board space required to fit the additional circuitry will, to some extent, be offset by the use of smaller connectors with fewer number of ways.

The circuit is suitable for driving red, green or yellow LEDs. Blue and white LEDs will only work at $V_{CC} \geq 4$ V.

(110572)

MOSFETs + Extras (2) / BTS432E2

By Raymond Vermeulen (Elektor Labs)

BTS432E2

In last month's column I discussed a MOSFET that allows the current through the FET to be measured efficiently. This time I will deal with an intelligent switch, that is, a MOSFET with built in logic and diodes. Such a component often offers functionalities such as safeguards against reverse-polarity, switching of inductive loads and protection against high currents and high temperatures, and ESD protection. Such features are particularly relevant in industrial and automotive environments. The clever switch below has all these features and even a few more.

(120226)

BTS432E2

The BTS432E2 is an intelligent high-side switch. It contains an N-channel MOSFET plus a charge pump for the gate and many protection measures. This switch is mainly intended for use in automotive power systems (12 V or 24 V) to control all kinds of resistive, inductive and capacitive loads (when used with inductive loads it is recommended to use a diode in parallel). This component can also be used at higher voltages; refer to the table. Designers experienced with MOSFETs and inductive loads are aware that the transients generated when the MOSFET is turned off can destroy the device and the logic connected to it. Thanks to all the protection measures built in, the BTS432E2 does not have any problems with this and it can therefore replace a relay in many applications.

Very handy is the ability to control this switch using a microcontroller which is operating at 2.7 V. A level shifter is built in specifically for this purpose, so that the gate will receive a proper drive signal despite the low voltage. There is also a status output; this open-drain output supplies a low level when the output is open circuit, there is a short-circuit to GND or V_{bb} , or when the temperature is too high. When the voltage is too low or too high the MOSFET will restart automatically, in this case the status pin is not activated. In addition there is protection against an incorrectly

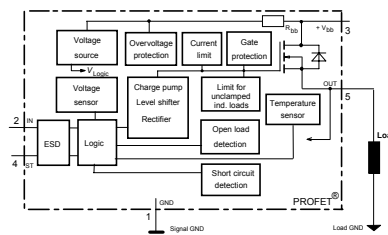


Figure 1. Block diagram and connection details.

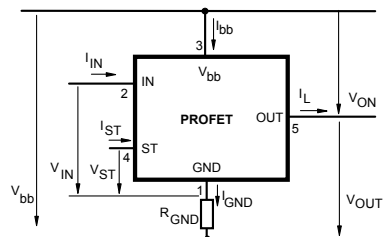


Figure 2. Currents and voltages.

connected voltage source and an open circuit ground connection.

The current limit is set to a much higher value for the first 400 μ s compared to the continuous current. This is very useful when switching capacitive loads or lamps. To limit the current when the voltage source is reversed it is possible to connect resistors in series with pins 1, 2, and 4. The current flowing through the so-called body diode will be limited by the load connected. But just how long this can be sustained depends on the amount of cooling of the component. If the switch in normal use becomes hotter than 150 °C, then it will switch off. Once the temperature has dropped sufficiently it will restart automatically.

Despite all the advantages there are also a number of drawbacks with these types of switches. The biggest is the on/off switching speed. Often, this is over 1000 times slower than a 'plain' MOSFET. Consequently the BTS432E2 is not suitable for applications that require fast switching. But generally speaking this type of MOSFET is an excellent electronic alternative for a relay.

Datasheet: www.infineon.com,
search for BTS432E2

Parameter	Condition	Value
On resistance R_{on}	$I_L = 2 \text{ A}$	30 m Ω (typ.)
Turn-on time t_{on}	90% V_{OUT}	160 μ s (typ.)
Input turn-on voltage $V_{IN(T+)}$	$T_j = -40 \text{ to } +150 \text{ }^\circ\text{C}$	2.4 V (max.)
Input turn-off voltage $V_{IN(T-)}$	$T_j = -40 \text{ to } +150 \text{ }^\circ\text{C}$	1.0 V (min.)
Undervoltage shutdown, $V_{bb(under)}$	$T_j = -40 \text{ to } +150 \text{ }^\circ\text{C}$	4.5 V (max.)
Overvoltage shutdown $V_{bb(over)}$	$T_j = -40 \text{ to } +150 \text{ }^\circ\text{C}$	42 V (min.)
Thermal overload trip temperature T_{jt}		150 °C
Nominal load current $I_{L(ISO)}$	$T_c = 85 \text{ }^\circ\text{C}$	9 A (min.)
Repetitive short circuit current limit $I_{L(SCr)}$	$T_j = 150 \text{ }^\circ\text{C}$	35 A (typ.)
Initial peak short circuit current limit $I_{L(SCp)}$	$T_j = 25 \text{ }^\circ\text{C}$	44 A (typ.)
Output clamp, voltage under V_{bb}	$I_L = 30 \text{ mA}$	58 V
Reverse battery $-V_{bb}$	Pin 3 to 1	-32 V (max.)

Intersil IM6100 Vintage Dev Kit

By Geoff Newton (UK)

This Dev kit was real state of the art stuff in 1977, but you had to be fairly dedicated to do much with it. There was no assembler or compiler. You had to write the program on paper, hand compile it and then load the memory with the required data using the keypad — not that there was all that much memory, only 256 words of 12 bits. The keypad and 7-segment display is in the bottom left of the board. The address of the selected memory cell and its contents is displayed by a set of eight 7-segment displays. The Keypad is 4 rows of 3 columns and most keys have several functions.

Because of the 12-bit format you had to use Octal as opposed to Hex which we mostly use today. There were no Up/Down arrow keys so to get to the next memory location you had to go through the whole cycle of entering the address, etc.

There is a 1 K*12 bit ROM which contains a “micro code interpreter” (*sic*) that deals with the keypad commands etc. and three edge connectors for the expansion boards. For the power supply there is a clip at the top of the board that takes four A type batteries stuffed into a cardboard tube to keep them in line.

I have only one option card, and that has a speaker and switch register, a row of LEDs and four 7-segment displays.

There was also an option card which gave you a whole 1 K (1024 words) of RAM, it also had a ROM card and an interface card with a UART and a parallel interface. All the latest accessories!

The Dev kit PCB is really quite well done and looks as it may have been done with a PCB design package.

Memory

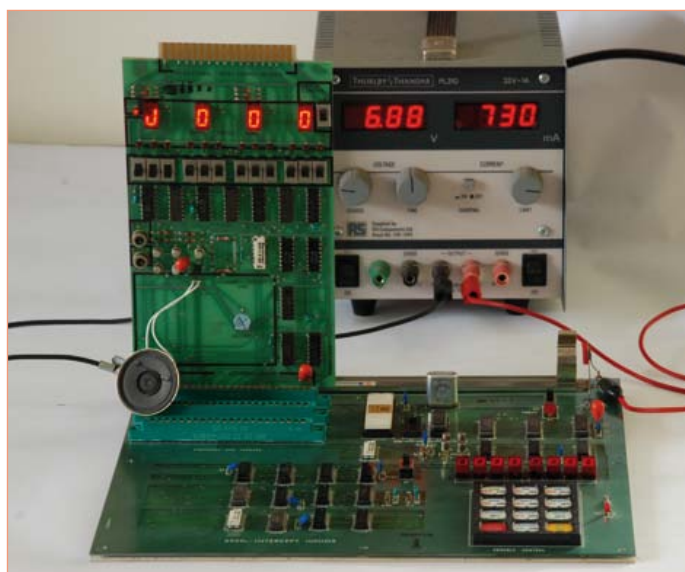
This kit has to have three chips each 256×4 bit to get its memory. The previous version had 12 256×1 bit chips. This was early days for memory chips and this emphasizes the problems they had with memory capacity. A main frame would only have 64 K×16 bit and each programmer had a 2 K partition to work in. If he or she needed more space it had to be done with ‘overlays’ from a magnetic tape.

Processor

Intersil developed the CMOS process in 1972 and the processor used in this Dev Kit followed in 1975.

At first glance the processor looks fairly good but when you delve into it a bit the flaws become apparent. Although it has up to an 8 MHz clock the processor takes at least 10 T states to do anything; even a NOP, meaning it is desperately slow. One conditional jump instruction takes 22 T states! The quartz crystal on this Dev Kit is only 2.4576 MHz which gives a minimum execution time for an instruction of well over 6 microseconds.

There's not much in the way of I/O space; only 64 addresses and only 12 bit addressing, i.e. 4 K.



It has only three registers and no stack pointer. To be able to return from a subroutine you have to save the return address in the first line of the subroutine, pick it at the end then jump back to the original address.

There is an interrupt, but you have to poll the I/O devices to find out which one called and really surprisingly there is DMA request and acknowledge lines.

The quirky 'PDP8-on-a-chip'



History Museum in Mountain View, CA [2]. It was once Princeton's and NASA's delight.

Sort of perversely some IM6100 pins are dedicated to certain functions like reading a 12-bit latch from the keypad. Strange to us, but in the context of the PDP8 completely natural. The PDP8 did not have an operating system as such (to start with) and had to be booted by using switches on the front panel.

Other pins form part of the I/O, when an I/O cycle is started c0,c1,c2 along with the skip pin Carry information from the I/O device back into the CPU and determine which type of operation is to happen. The Skip input pin causes the next instruction to be skipped. Riveting stuff! A 'link' output pin seems to be the Carry flag.

The IM6100 uses the PDP-8 instruction set and so is very much a design that is halfway between the bit slice technology and the fully integrated (modern) processor. Rather primitive really and awkward to program, but the PDP8 was popular in its time and so a single chip version seemed a good idea. The IM6100 did find its way into some military applications. There was even a version of FORTRAN for it, but it was all killed off in 1982 when the IBM PC was produced based on Intel's 8088.

(120161)

[1] <http://en.wikipedia.org/wiki/PDP-8>

[2] www.computerhistory.org/

PIN ASSIGNMENTS			
PIN	SYMBOL	ACTIVE LEVEL	DESCRIPTION
1	V _{cc}	H	Supply voltage.
2	RUN	H	The signal indicates the runstate of the CPU and may be used to power down the external circuitry.
3	DMAGNT	H	Direct Memory Access Grant—DMA lines are tri-stateable.
4	DMAREQ	L	Direct Memory Access Request—DMA is granted at the end of the current instruction. Upon DMA grant, the CPU suspends program execution until the DMAREQ line is released.
5	CPREQ	L	Control Panel Request—a dedicated interrupt which bypasses the normal device interrupt request structure.
6	RUN/HLT	L	Pulsing the Run/Halt line causes the CPU to alternately run and halt by changing the state of the internal RUN/HLT flip flop.
7	RESET	L	Cleares the AC and loads 7777 into the
10	LX/MAR	H	The Load External Address Register is used to store memory and peripheral address externally.
11	WAIT	L	Indicates that peripherals or external memory is not ready to transfer data. The CPU state gets extended as long as WAIT is active. The CPU is in the lowest power state with clocks running.
12	XT ₀	H	External coded minor cycle timing—signifies output transfers from the IM6100.
13	XT ₁	H	External coded minor cycle timing—used in conjunction with the Select Lines to specify read or write operations.
14	OSC OUT		Crystal input to generate the internal timing (also external clock input).
15	OSC IN		See Pin 14—OSC OUT (also external clock ground).
16	DX ₀		Delay—multiplexed data in, data out



Comparison with the Z80, which is more or less contemporary, shows up something else. The folks at Zilog made a quantum leap and designed the Z80 as a complete microprocessor with only the data, address and relevant control lines brought out to pins. In contrast the IM6100 appears to be much more like part of a bit slice system integrated into a single chip, and in fact that that's what it is.

PDP8 legacy

The IM6100 is a single chip version of DEC's legendary PDP8 mini computer from the 1960s, also pictured here for your amusement (rare /E version; source: [WikiMedia Commons](#)). Go check out the PDP8 on Wikipedia [1] and even better at the [awesome Computer](#)

Bit Slice

In a bit slice system the Central Processor Unit is a whole circuit board (i.e. 15 inches × 18 inches) full of dual in line (DIL) chips. Each element of the processor is implemented as separate chips, so for instance a 16-bit ALU (arithmetic logic unit) would be 4 off 74LS181 4-bit slices, likewise the State Machine was made up from LS74 D-type latches, and so on.. The circuit board had an edge connector which was the equivalent of pins on a microprocessor chip.

Other circuit boards provided the memory, the I/O, the tape drive interface, etc. and the whole caboodle was mounted in a 19" rack frame with its own power supply.

When colour monitors came along that created another great box full of circuit boards and another power supply.

I had a Data General Eclipse for a while and it needed 15 amps at 240 volts to run it!

Hexadoku

Puzzle with an electronics touch

We're happy to present yet another Hexadoku for the puzzle fans among our readers (and their spouses/ girlfriends — hi there!). With 16 x 16 cells to look at a Hexadoku is a real challenge to solve. Enter the right numbers or letters A-F in the open boxes, find the solution, send it to us and you automatically enter the prize draw for one of four Elektor Shop vouchers.

The instructions for this puzzle are straightforward. Fully geared to electronics fans and programmers, the Hexadoku puzzle employs the hexadecimal range 0 through F. In the diagram composed of 16 x 16 boxes, enter numbers such that **all** hexadecimal numbers 0 through F (that's 0-9 and A-F) occur once only in each row, once

in each column and in each of the 4x4 boxes (marked by the thicker black lines). A number of clues are given in the puzzle and these determine the start situation. Correct entries received enter a draw for a main prize and three lesser prizes. All you need to do is send us the numbers in the grey boxes.

Solve Hexadoku and win!

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Prize winners

The solution of the March 2012 Hexadoku is: 78BE0.

The Elektor £80.00 voucher has been awarded to Wolfgang Kallauch (Germany).

The Elektor £40.00 vouchers have been awarded to Luis Fernando Fox González (Spain),

Francis Biette (France), and Bruno Couillard (Canada).

Congratulations everyone!

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				C		1		3	E		F			2	7
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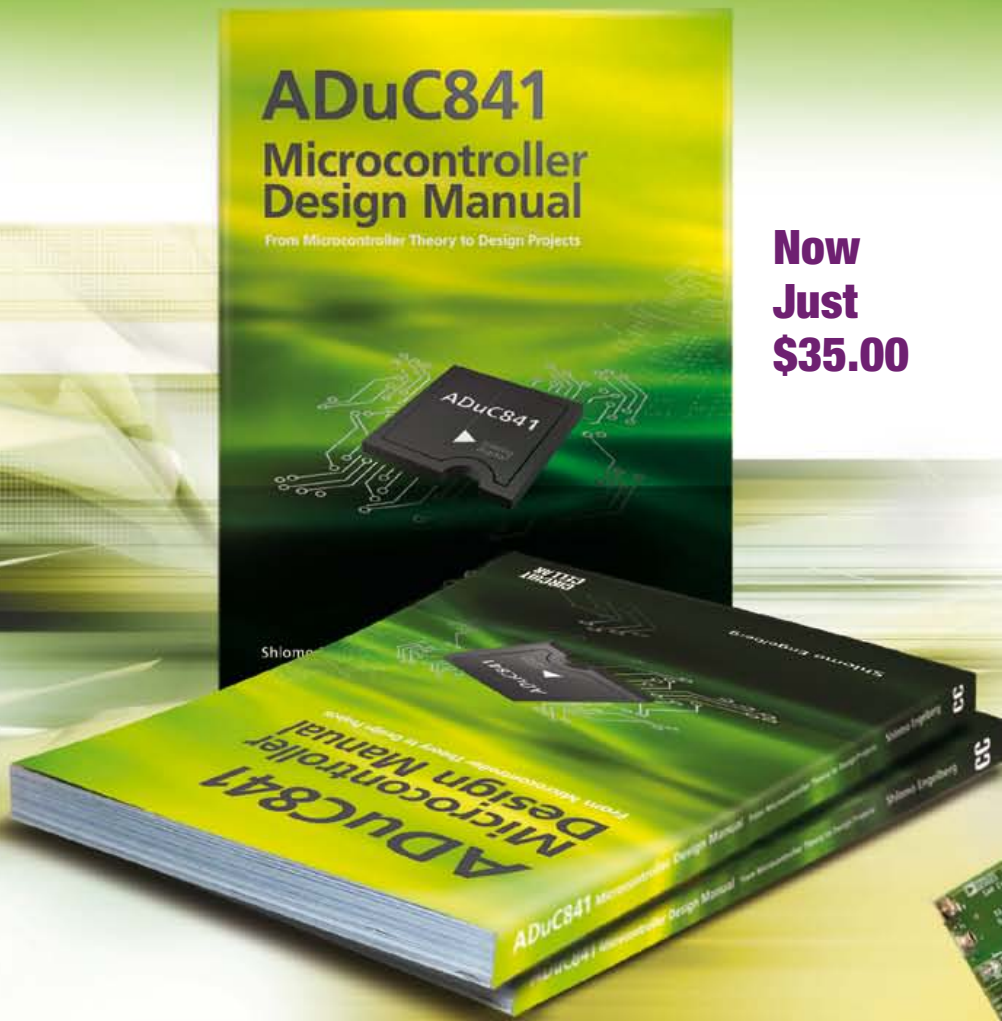
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2	6	D	C	3	4	7	B	9	5	A	F	0	1	8	E
B	F	0	1	9	A	5	8	4	C	7	E	2	3	D	6
5	8	1	2	0	9	D	3	7	A	C	6	F	B	E	4
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0	9	A	D	F	6	4	C	E	1	2	B	7	5	3	8
C	3	F	6	7	8	B	E	0	4	5	9	D	2	1	A
4	0	B	8	6	D	2	9	5	3	1	A	E	7	F	C
D	2	C	3	1	B	8	4	F	0	E	7	9	A	6	5
9	E	7	F	5	3	0	A	6	2	D	C	B	8	4	1
1	A	6	5	C	E	F	7	8	9	B	4	3	D	0	2
F	1	2	0	4	C	9	5	A	7	6	3	8	E	B	D
3	D	E	7	8	2	A	6	C	B	4	0	1	F	5	9
6	C	5	9	B	1	3	F	D	E	8	2	4	0	A	7
A	B	8	4	D	7	E	0	1	F	9	5	C	6	2	3

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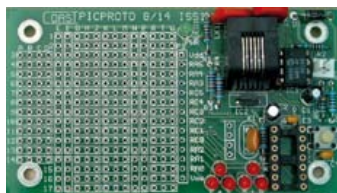
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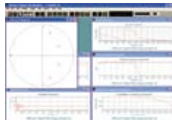
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Art.# 110320-91

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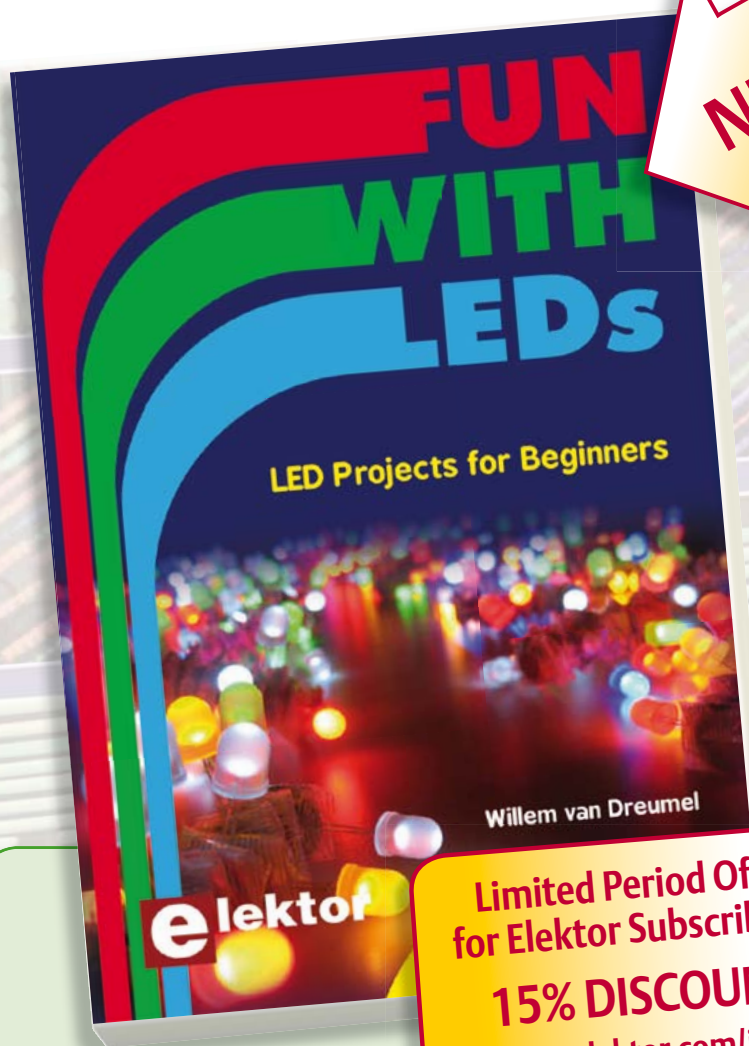
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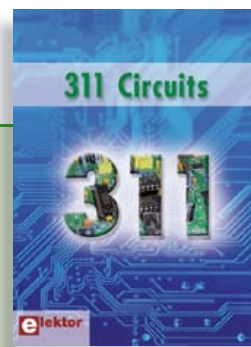
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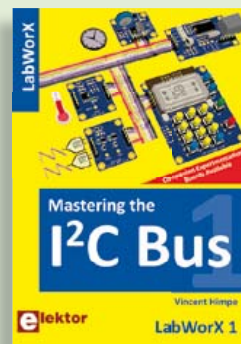


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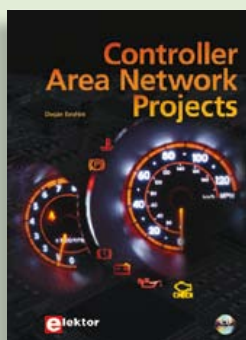


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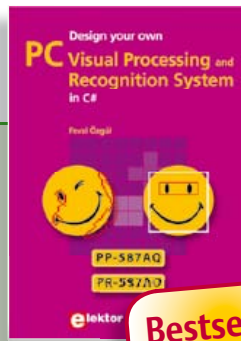


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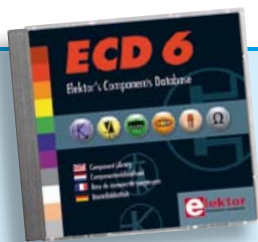
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(May 2012)

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(April 2012)

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RS485-Relay board, assembled and tested

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(March 2012)

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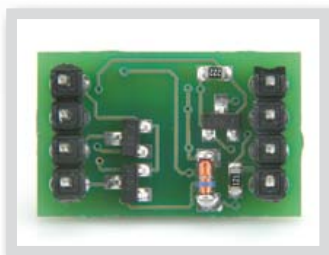
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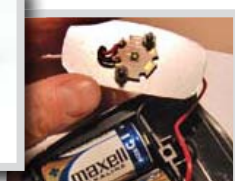
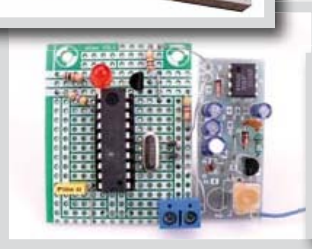
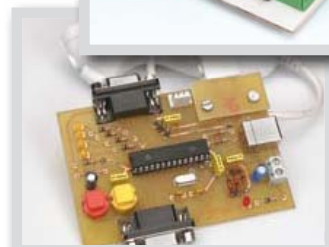
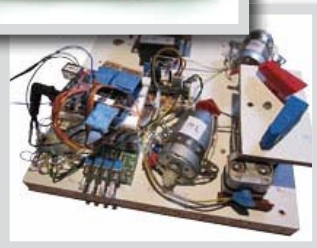


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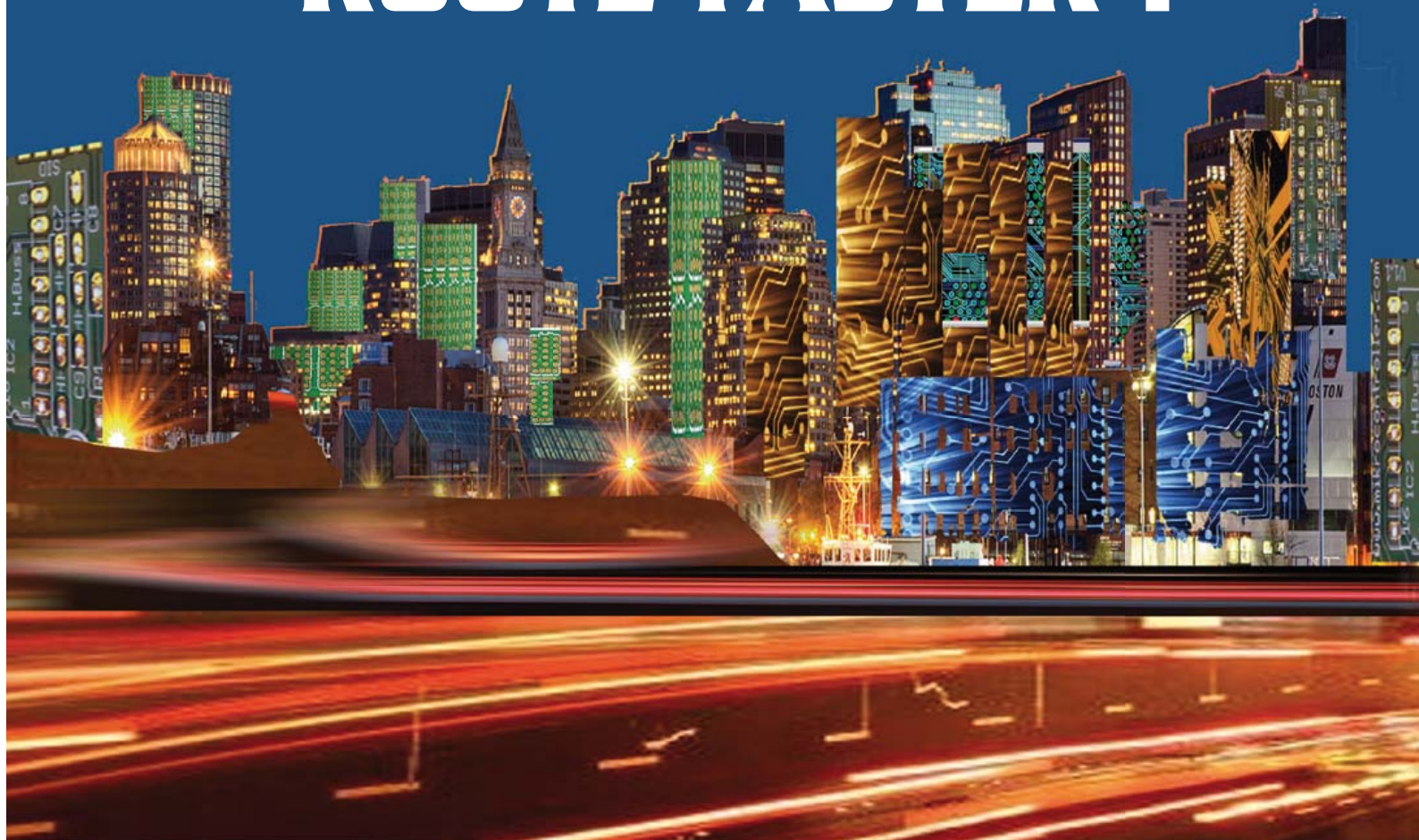
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